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(12) **United States Patent**
Verdier et al.(10) **Patent No.:** **US 9,121,031 B2**
(45) **Date of Patent:** **Sep. 1, 2015**(54) **METHODS AND COMPOSITIONS FOR
REGULATING PRODUCTION OF
PROANTHOCYANIDINS**(75) Inventors: **Jerome A. Verdier**, Ardmore, OK (US);
Jian Zhao, Ardmore, OK (US); **Richard
A. Dixon**, Sulphur, OK (US); **Michael
K. Udvardi**, Ardmore, OK (US)(73) Assignee: **The Samuel Roberts Noble
Foundation, Inc.**, Ardmore, OK (US)(*) Notice: Subject to any disclaimer, the term of this
patent is extended or adjusted under 35
U.S.C. 154(b) by 560 days.(21) Appl. No.: **13/444,507**(22) Filed: **Apr. 11, 2012**(65) **Prior Publication Data**

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11, 2011.(51) **Int. Cl.**
C12N 15/82 (2006.01)
C07K 14/415 (2006.01)(52) **U.S. Cl.**
CPC **C12N 15/825** (2013.01); **C07K 14/415**
(2013.01)(58) **Field of Classification Search**
None
See application file for complete search history.(56) **References Cited****U.S. PATENT DOCUMENTS**7,709,701 B2 5/2010 Dixon et al.
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Primary Examiner — Russell Kallis(74) *Attorney, Agent, or Firm* — Dentons US LLP(57) **ABSTRACT**

The invention provides methods and compositions for the
modulation of proanthocyanidin ("PA;" condensed tannin)
production in plants. The methods of the invention allow
creation of plants having novel phenotypes, such as altera-
tions in levels of PA or in the types of tissues in which PAs
are produced. Altered expression of PA in plants may be
achieved, for instance without significantly affecting antho-
cyanin content or overall secondary metabolite profiles.
Alternatively, expression of PA in plants may be achieved
while also affecting anthocyanin content.

(56)

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FIG. 1

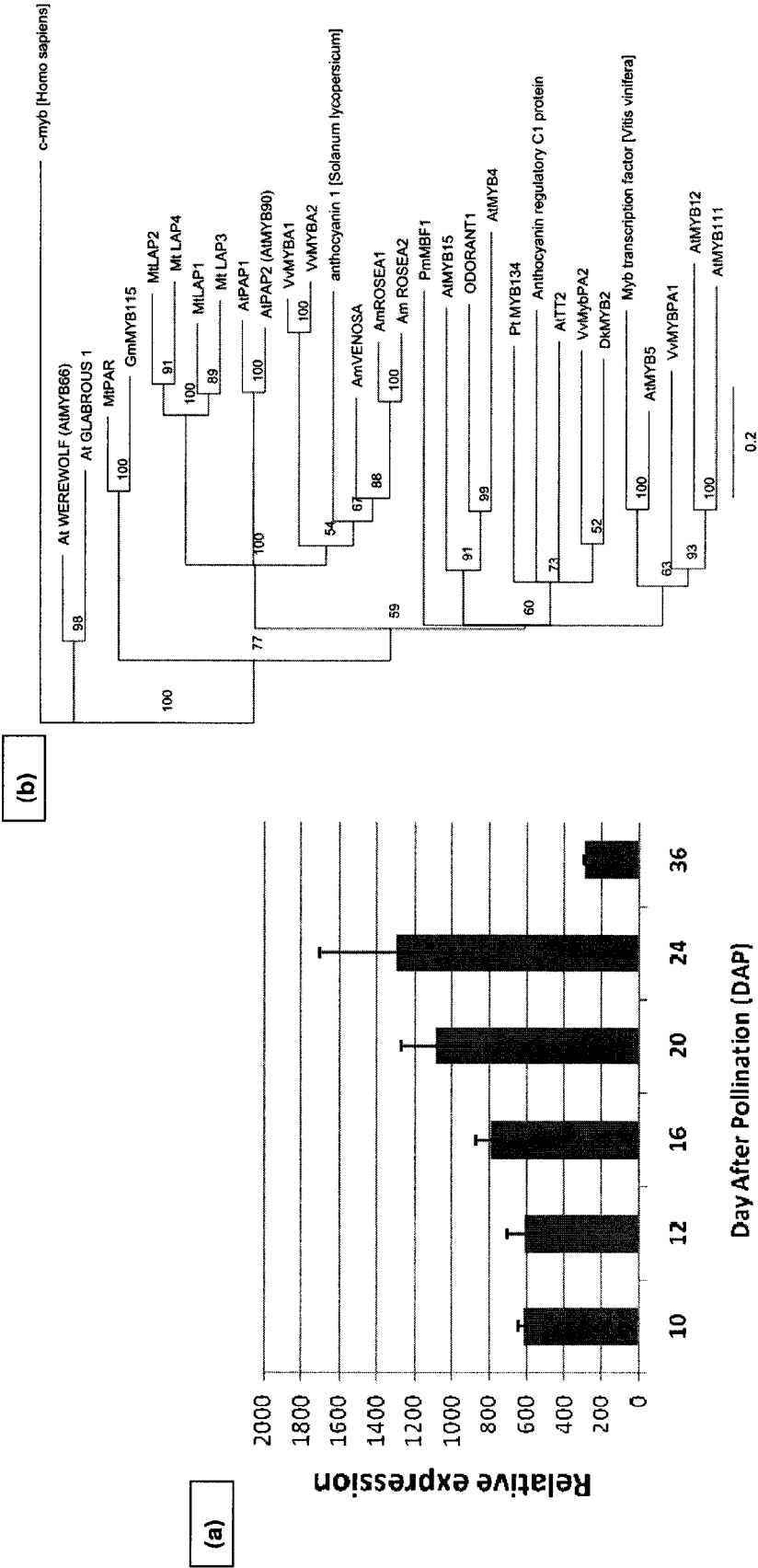


FIG. 2

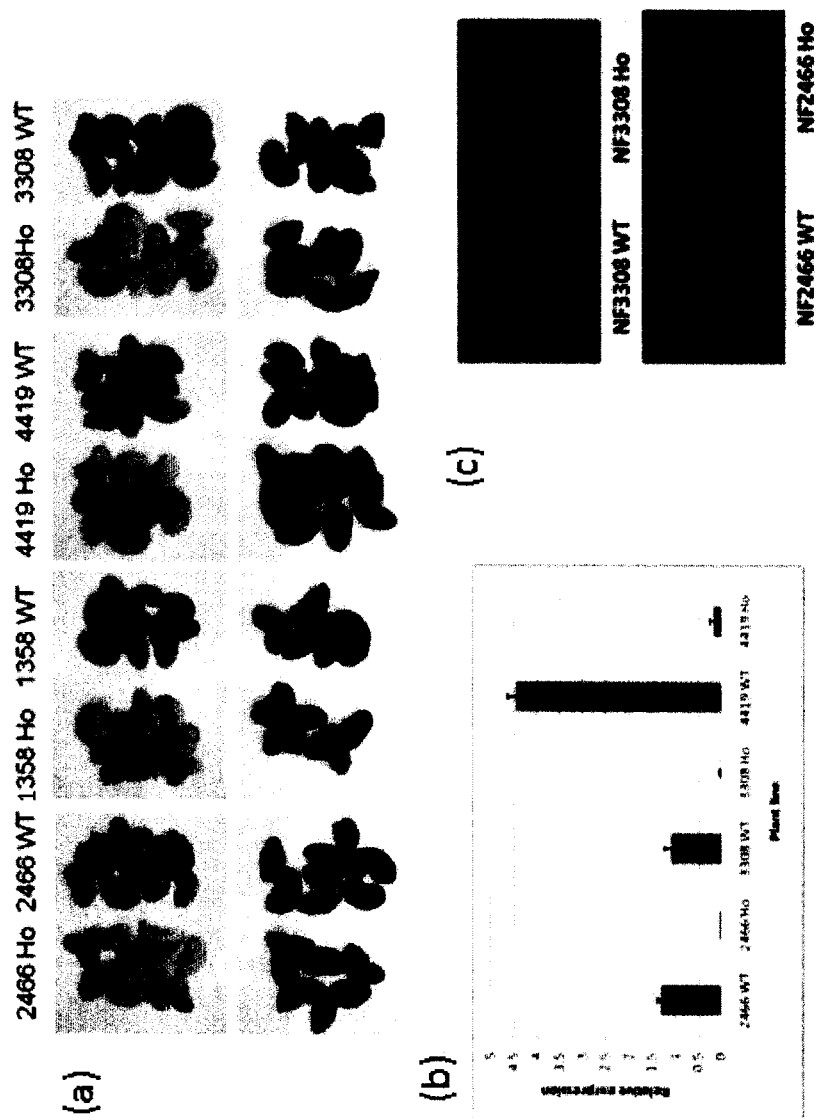


FIG. 3

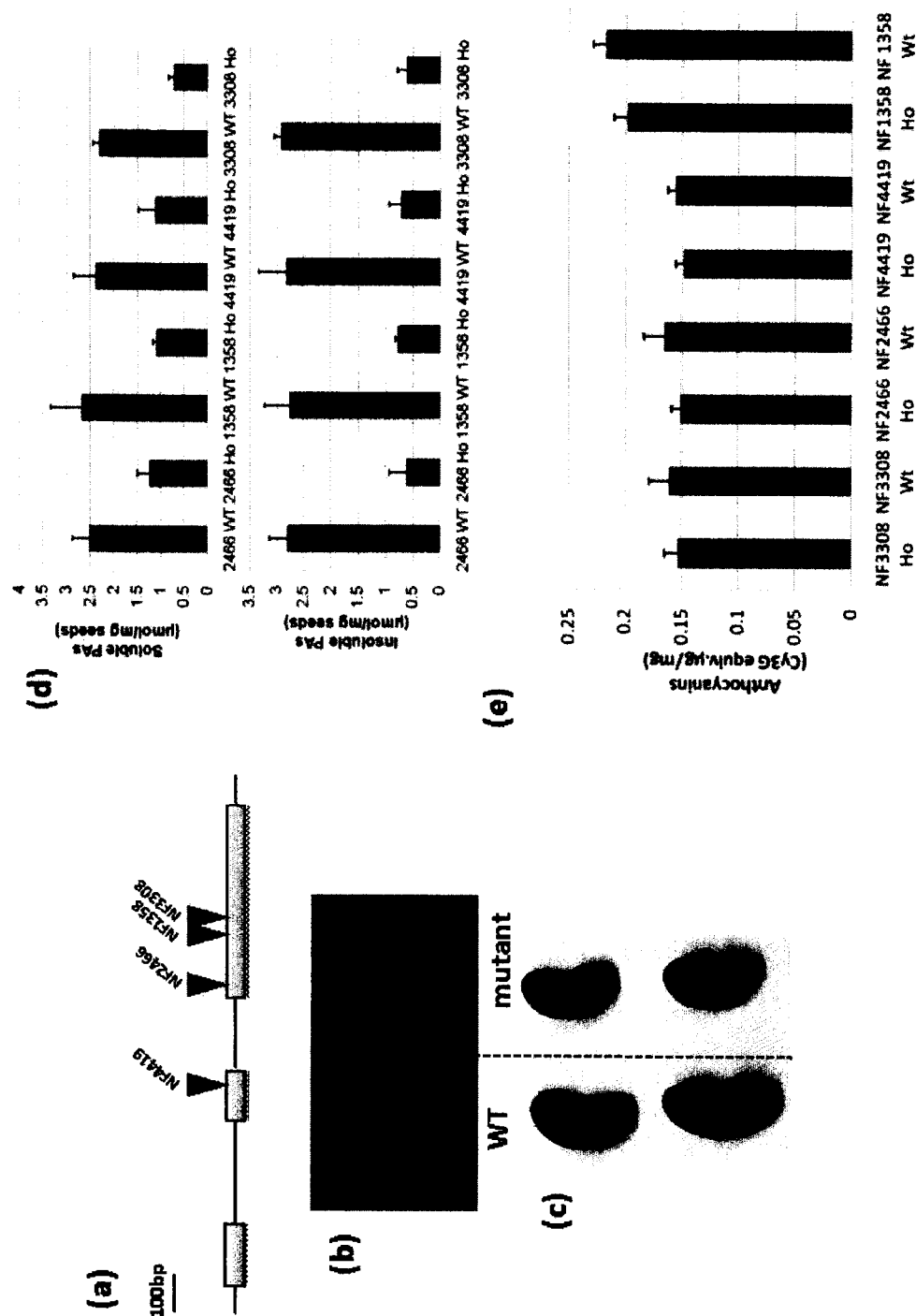


FIG. 4

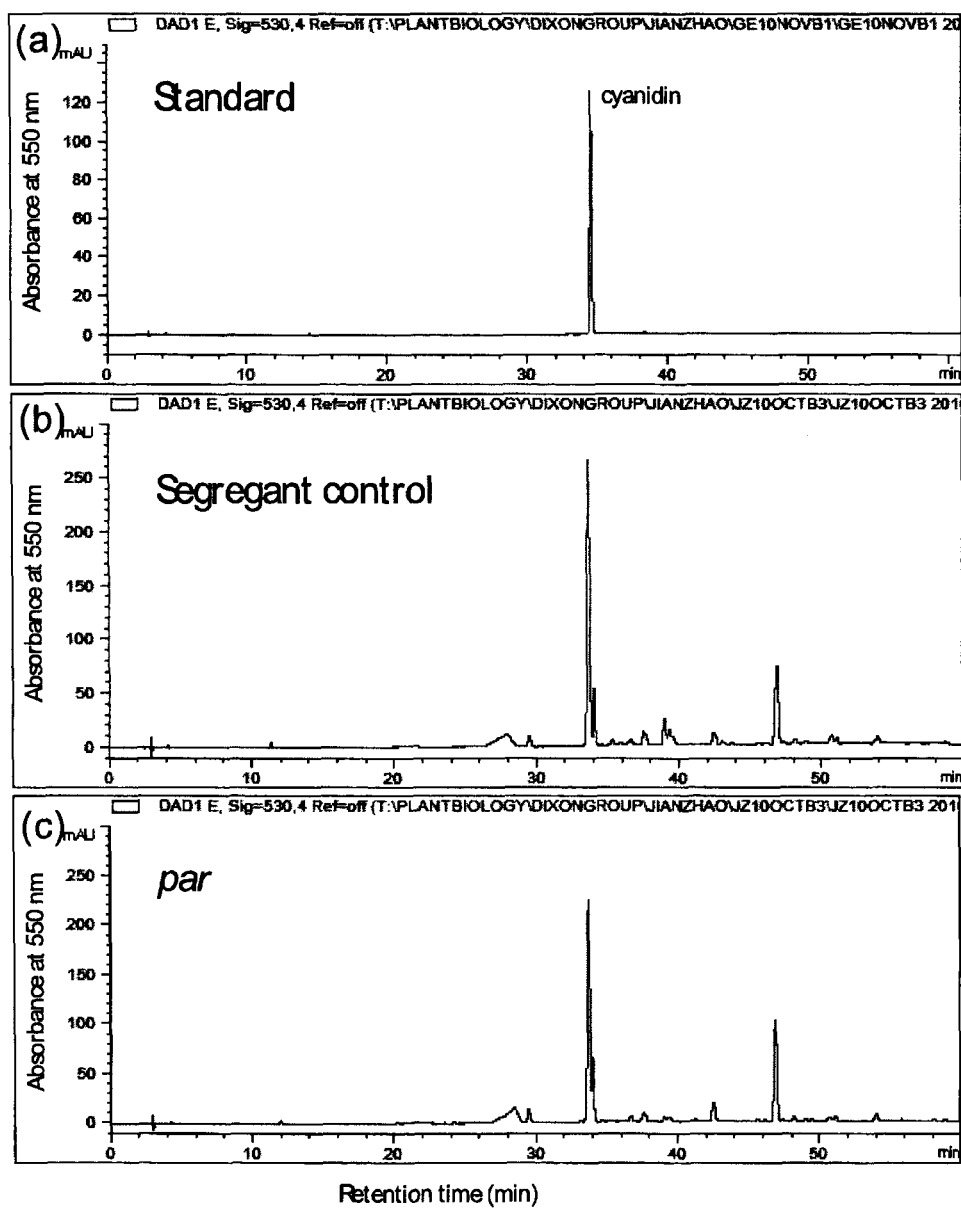


FIG. 5

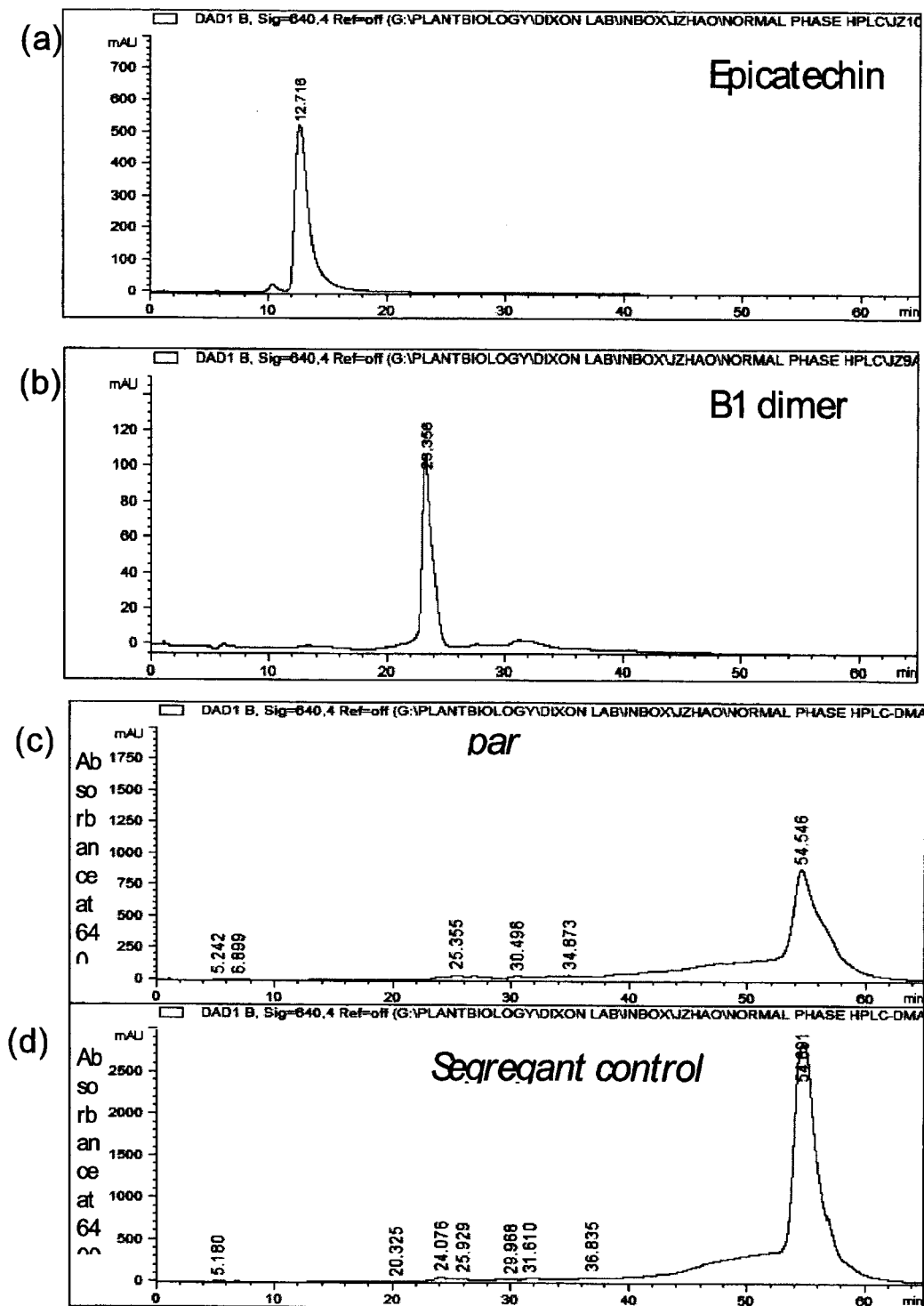


FIG. 5 (continued)

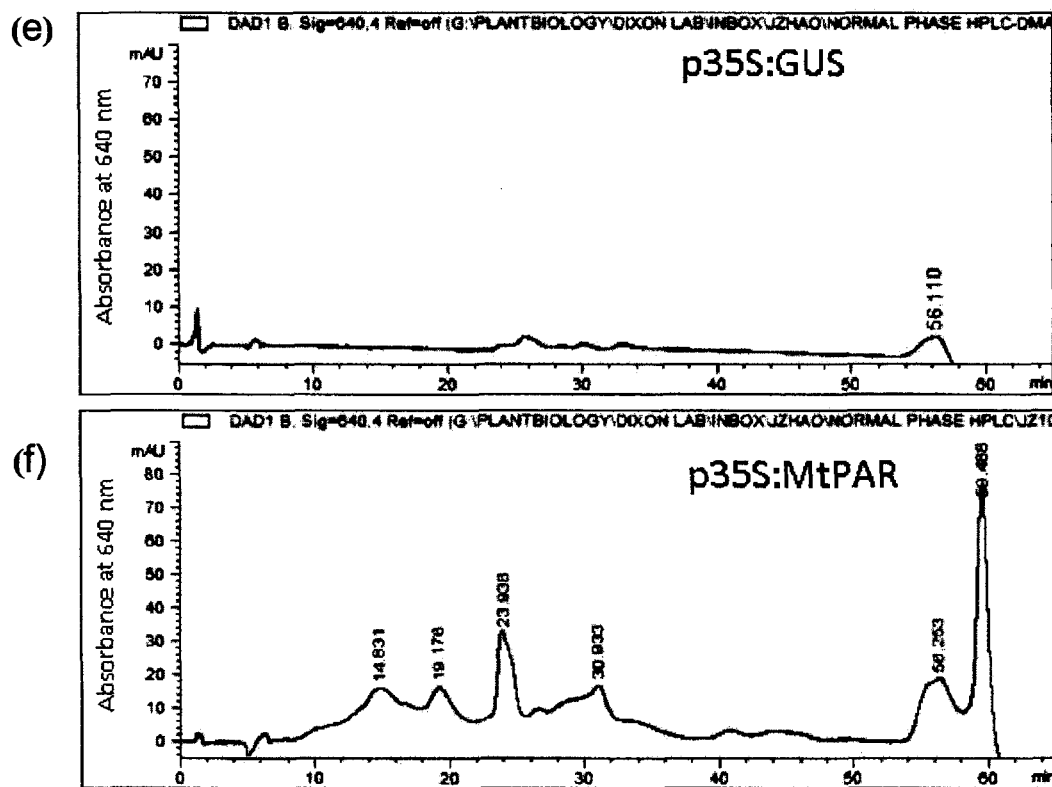


FIG. 6

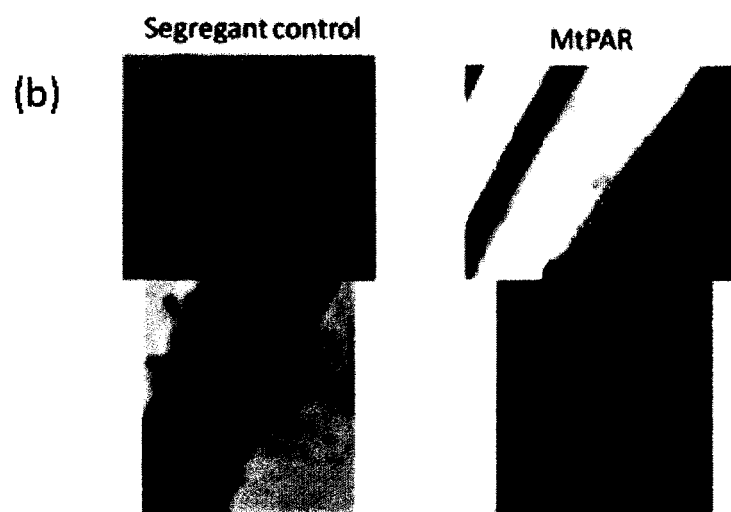
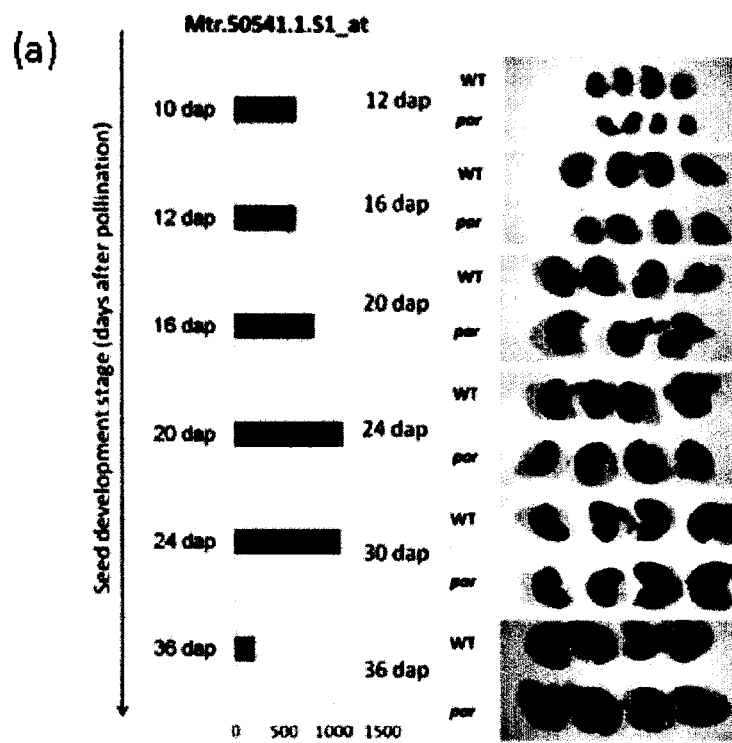


FIG. 7

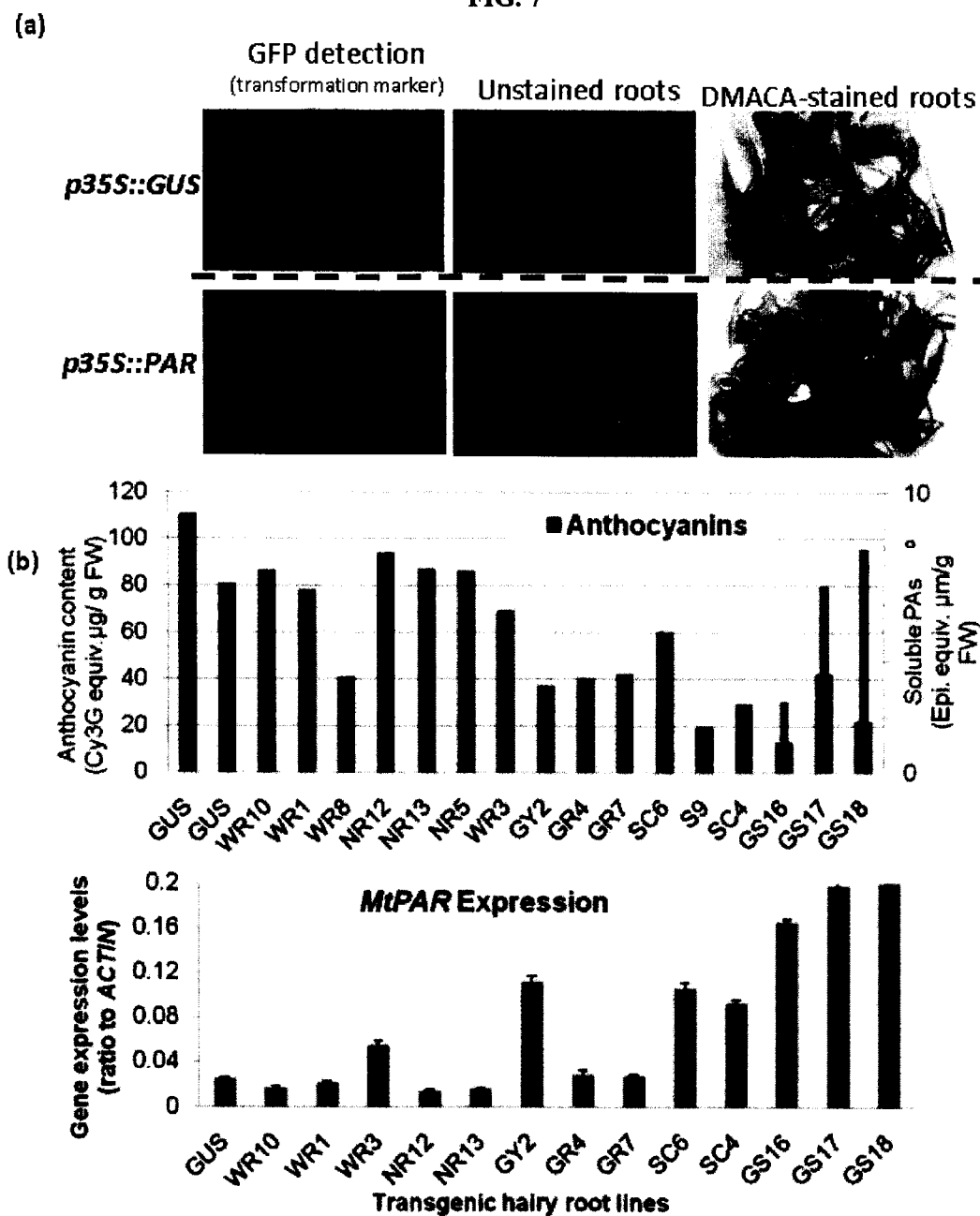
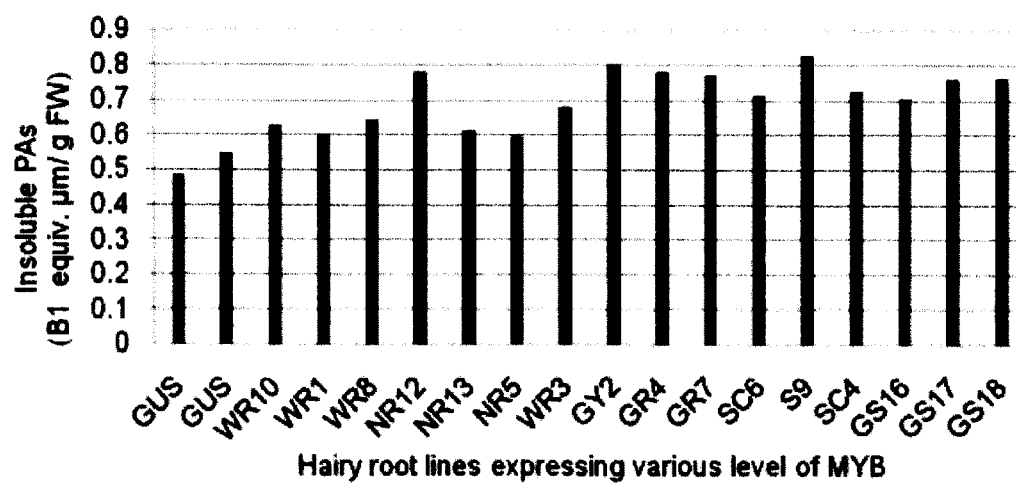
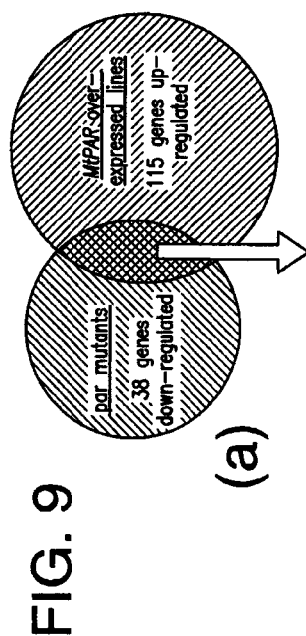


FIG. 8





Probesets	Target Description	Representative Public ID	Tnt1 mutant lines		Hairy root transformants	
			Ratio par/Ck	p-value	Ratio PAR/GUS	q-value
Mtr.20567.1.S1_at	Type III polyketide synthase; Naringenin-chalcone synthase	1115.m00010	0.006838	0.025969	4.701298	0
Mtr.36333.1.S1_at	similar to UP Q84J44 (Q84J44) Flavonoid 3'-hydroxylase (Fragment), partial (21%)	BE248436	0.027408	0.008888	0.088535	9.24E-13
Mtr.6517.1.S1_at	similar to UP Q84J65 (Q84J65) Gray pubescence flavonoid 3'-hydroxylase, partial (49%)	BQ147749	0.049162	0.005732	2.637451	0
Mtr.14017.1.S1_at	weekly similar to UP LDOX_ARATH (Q96323) Leucoanthocyanidin dioxygenase (LDOX) Anthocyanidin synthase (ANS), partial (19%)	TC99980	0.062597	0.030434	3.857393	0
Mtr.39897.1.S1_at	similar to UP P93697 (P93697) CPRD12 protein, partial (61%)	TC105988	0.079569	0.016543	2.06289	3.63E-22
Mtr.14428.1.S1_at	Naringenin-chalcone synthase; Type III polyketide synthase	1115.m00011	0.11897	0.101612	2.235309	2.14E-70
Mtr.44985.1.S1_at	Anthocyanidin reductase, complete	TC98546	0.165667	0.077882	2.333918	2.5E-54
Mtr.50541.1.S1_at	MIPAR gene, Myb, DNA-binding; Homeodomain-like	1054.m00009	0.196626	0.078708	104.6917	0
Mtr.28714.1.S1_at	homologue to PRF 1609233A 226868 1609233A chalcone synthase 3, {Sinapis alba}, partial (12%)	B1311259	0.214729	0.078186	2.332891	5.3E-181
Mtr.10917.1.S1_at	similar to UP C773_S0YBN (Q48929) Cytochrome P450 77A3, partial (95%)	TC108343	0.367035	0.011932	4.242139	0
Mtr.26465.1.S1_s_at	similar to UP PEAM_SPIOL (Q9M571) Phosphoethanolamine N-methyltransferase	1520.m00027	0.420515	0.000341	2.180135	0.000483
Mtr.37221.1.S1_at	homologue to UP Q43437 (Q43437) Photosystem II type I chlorophyll a/b-binding protein precursor, complete	TC100154	0.476583	0.038178	3.032851	6.1E-150

(b)

FIG. 10

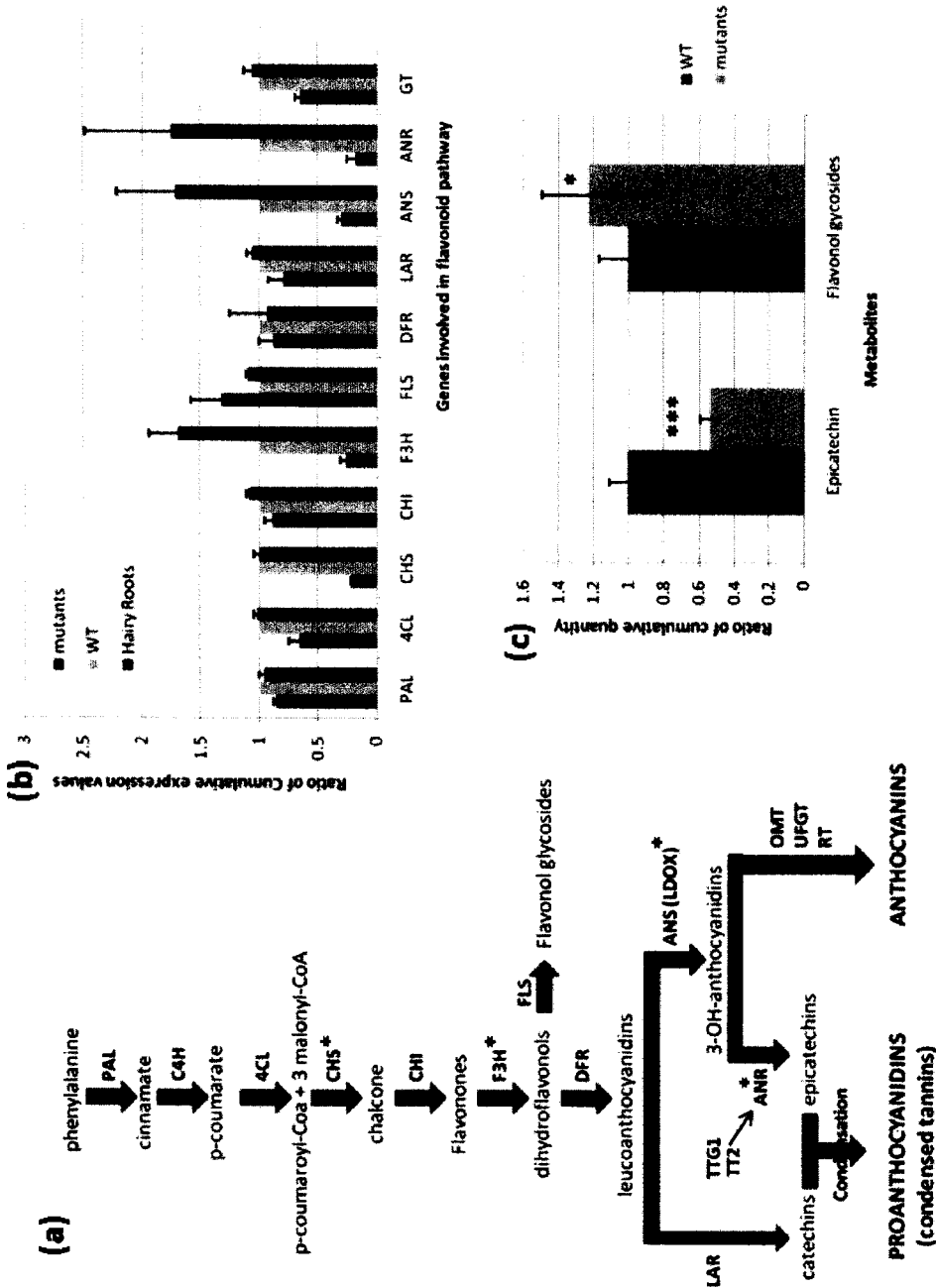
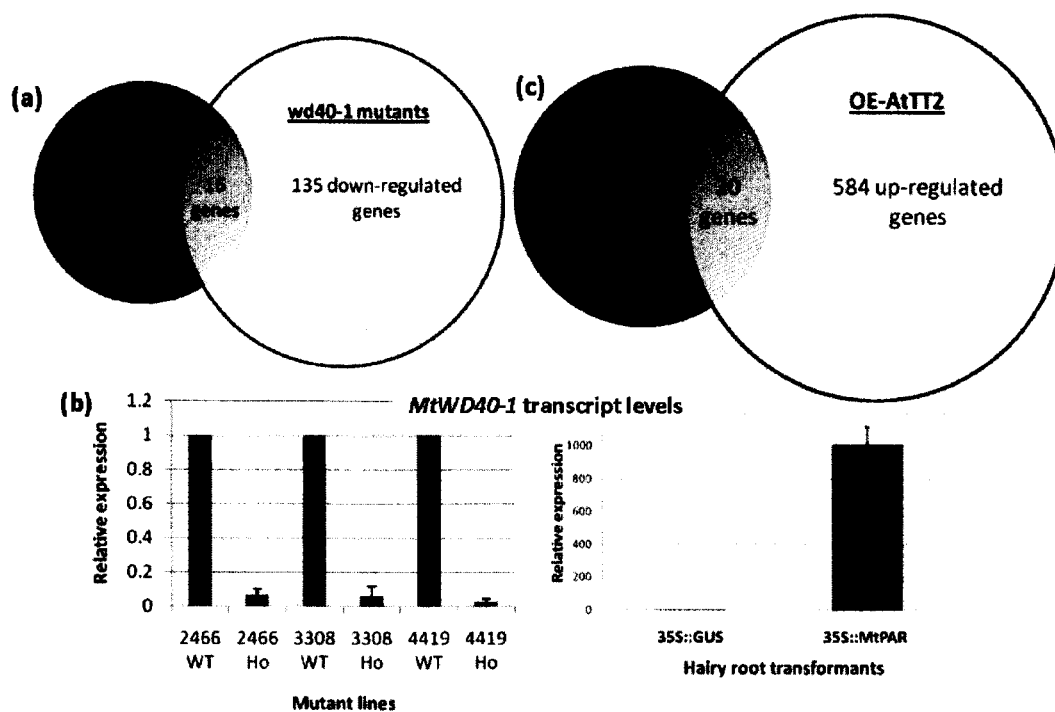


FIG. 11



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METHODS AND COMPOSITIONS FOR REGULATING PRODUCTION OF PROANTHOCYANIDINS

This application claims the priority of U.S. Provisional Appl. Ser. No. 61/474,224, filed Apr. 11, 2011, the entire disclosure of which is incorporated herein by reference.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

The disclosed subject matter was developed in part with funding from United States Department of Agriculture grant USDA\CSREES-NRI plant genome project 2006-35300-17143. The government may have certain rights in the invention.

INCORPORATION OF SEQUENCE LISTING

The sequence listing contained in the file named "NBLE080US_ST25.txt", which is 12.1 kilobytes (size as measured in Microsoft Windows®) and was created on Apr. 11, 2012, is filed herewith by electronic submission and is incorporated by reference herein.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention generally relates to plant genetics. More specifically, the invention relates to genes and enzymes involved in the biosynthesis of anthocyanins, proanthocyanidins, and tannins, and methods for use thereof.

2. Description of the Related Art

Proanthocyanidins ("PAs," also called condensed tannins ("CTs")) are oligomers of flavan-3-ol units and are prominent, colored compounds in seed coats, leaves, fruits, flowers and bark of many plant species. PAs and their monomeric building blocks such as catechin and epicatechin are potent antioxidants with beneficial effects on human health, including cardio-protective, anticancer and anti-inflammatory activities. In addition, PAs from various plants have beneficial effects on cardiac health and immune responses. PAs can therefore affect the nutritional quality of human and animal food.

SUMMARY OF THE INVENTION

In one aspect, the invention provides a DNA nucleic acid comprising a DNA sequence selected from the group consisting of: (a) a nucleic acid sequence encoding the polypeptide sequence of SEQ ID NO:1; (b) a nucleic acid sequence comprising the sequence of SEQ ID NO:2; (c) a nucleic acid sequence that hybridizes to SEQ ID NO:2 under conditions of 1×SSC, and 65° C. and encodes a polypeptide which regulates flavonoid synthesis; (d) a nucleic acid sequence encoding a polypeptide with at least 85% amino acid identity to SEQ ID NO:1 and encodes a polypeptide which regulates flavonoid synthesis; (e) a nucleic acid sequence with at least 85% identity to SEQ ID NO:2 and encodes a polypeptide which regulates flavonoid synthesis; and (f) a complement of a sequence of (a)-(e) or a fragment thereof wherein the nucleic acid sequence regulates flavonoid synthesis; wherein the DNA sequence is operably linked to a heterologous promoter. In certain embodiments, the sequence may have at least 90%, at least 95%, at least 98%, or at least 99% sequence identity with SEQ ID NO:1 or SEQ ID NO:2.

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The invention further provides a recombinant vector comprising a DNA sequence as provided herein. The recombinant vector may further comprise at least one additional sequence chosen from the group consisting of: a regulatory sequence, a selectable marker, a leader sequence and a terminator. In particular embodiments, the polypeptide that activates anthocyanin or proanthocyanidin biosynthesis is selected from the group consisting of: phenylalanine ammonia-lyase (PAL), cinnamate 4-hydroxylase (C4H), 4-coumarate:CoA ligase (4CL), chalcone synthase (CHS), chalcone isomerase (CHI), flavanone 3-hydroxylase (F3H), dihydroflavonol reductase (DFR), anthocyanidin synthase (ANS), leucoanthocyanidin reductase (LAR), anthocyanidin reductase (ANR), a proanthocyanidin or anthocyanidin glucosyltransferase (GT), LAP1, LAP2, LAP3, LAP4, or AtPAP1 (production of anthocyanin pigment). The recombinant vector may further be defined as comprising a promoter, wherein the promoter is a plant developmentally-regulated, organelle-specific, inducible, tissue-specific, constitutive, or cell-specific promoter. The recombinant vector may, in certain embodiments, be defined as an isolated expression cassette.

Another aspect of the invention comprises an isolated polypeptide having at least 85% amino acid identity to the amino acid sequence of SEQ ID NO:1, or a fragment thereof, which regulates flavonoid synthesis. In certain embodiments, the flavonoid is an anthocyanin or a proanthocyanidin.

Yet another aspect of the invention comprises a transgenic plant transformed with a DNA molecule comprising a DNA sequence selected from the group consisting of: (a) a nucleic acid sequence encoding the polypeptide sequence of SEQ ID NO:1; (b) a nucleic acid sequence comprising SEQ ID NO:2; (c) a nucleic acid sequence that hybridizes to SEQ ID NO:2 under conditions of 1×SSC, and 65° C. and encodes a polypeptide which regulates flavonoid synthesis; (d) a nucleic acid sequence encoding a polypeptide with at least 85% amino acid identity to SEQ ID NO:1 and which regulates flavonoid synthesis; (e) a nucleic acid sequence with at least 85% identity to SEQ ID NO:2 and that encodes a polypeptide which regulates flavonoid synthesis; and (f) a complement of a sequence of (a)-(e), or a fragment thereof, wherein the nucleic acid sequence is operably linked to a heterologous promoter. Seed of such a plant, and progeny of such a plant of any subsequent generation, each comprising the selected DNA, are another aspect of the invention. In certain embodiments the invention provides such a transgenic plant, wherein the plant is a forage crop. In particular embodiments the plant is a legume. In more particular embodiments, the plant is a *Medicago* plant, such as an alfalfa plant. A plant that expresses the DNA molecule and exhibits altered flavonoid (e.g. proanthocyanidin and/or anthocyanin) biosynthesis in selected tissues relative to those tissues in a second plant that differs from the transgenic plant only in that the selected DNA is absent is also provided. In certain embodiments, proanthocyanidin and/or anthocyanin biosynthesis is increased. In other embodiments, proanthocyanidin and/or anthocyanin biosynthesis is decreased.

The transgenic plant may further be defined, in certain embodiments, as one that is transformed with a selected DNA which regulates flavonoid synthesis, selected from the group consisting of SEQ ID NO:1 or a fragment thereof. In other embodiments, the transgenic plant may further be defined as transformed with a selected DNA sequence complementary to a sequence which regulates flavonoid synthesis, e.g. proanthocyanidin and/or anthocyanin biosynthesis. In particular embodiments, the transgenic plant is further defined as transformed with and comprising a DNA sequence complementary to the MtPAR sequence of SEQ ID NOs:2-3, or a frag-

ment thereof, such as a sequence comprising 17 or more, 19 or more, or 21-24 or more contiguous nucleotides complementary to SEQ ID NO:2 or SEQ ID NO:3. In other embodiments, the transgenic plant is further defined as transformed with a DNA sequence encoding the polypeptide of SEQ ID NO:1. The invention also provides such a transgenic plant, wherein the plant is a forage legume. In particular embodiments, the plant is a *Medicago* plant. In particular embodiments, the plant is alfalfa (*Medicago sativa*).

In some embodiments, the transgenic plant is further defined as comprising proanthocyanidins in tissues other than seeds. In certain embodiments the tissues are selected from the group consisting of leaves, stems, and roots. In other embodiments, the tissues are defined as tissues destined for animal consumption.

In other embodiments, the transgenic plant comprises a nucleic acid selected from the group consisting of: (a) a nucleic acid sequence encoding the polypeptide sequence of SEQ ID NO:1; (b) a nucleic acid sequence comprising the sequence of SEQ ID NO:2; (c) a nucleic acid sequence that hybridizes to SEQ ID NO:2 under conditions of 1×SSC, and 65° C. and encodes a polypeptide which regulates flavonoid synthesis; (d) a nucleic acid sequence encoding a polypeptide with at least 85% amino acid identity to SEQ ID NO:1 and encodes a polypeptide which regulates flavonoid synthesis; (e) a nucleic acid sequence with at least 85% identity to SEQ ID NO:2 and encodes a polypeptide which regulates flavonoid synthesis; and (f) a complement of a sequence of (a)-(e), or a fragment thereof wherein the nucleic acid sequence is operably linked to a heterologous promoter, is further defined as comprising at least one additional transgenic coding sequence chosen from the group consisting of: a regulatory sequence, a sequence that encodes a polypeptide that activates anthocyanin or proanthocyanidin biosynthesis, a selectable marker, a leader sequence and a terminator.

In still further embodiments, the polypeptide that activates anthocyanin or proanthocyanidin biosynthesis is selected from the group consisting of: phenylalanine ammonia-lyase (PAL), cinnamate 4-hydroxylase (C4H), 4-coumarate:CoA ligase (4CL), chalcone synthase (CHS), chalcone isomerase (CHI), flavanone 3-hydroxylase (F3H), dihydroflavonol reductase (DFR), anthocyanidin synthase (ANS), leucoanthocyanidin reductase (LAR), anthocyanidin reductase (ANR), a proanthocyanidin or anthocyanidin glucosyltransferase (GT), LAP1, LAP2, LAP3, LAP4, or AtPAP1 (production of anthocyanin pigment). The transgenic plant may further be defined as a fertile R_0 transgenic plant, or as a progeny plant of any generation of a fertile R_0 transgenic plant, wherein the transgenic plant comprises the selected DNA.

Also provided by the invention is a cell transformed with a DNA molecule as provided herein. In certain embodiments, the cell is a plant cell. In other embodiments, the cell is a bacterial cell.

The invention also provides a method of producing a plant with increased proanthocyanidin biosynthesis, comprising expressing in the plant an isolated nucleic acid sequence selected from the group consisting of: (a) a nucleic acid sequence encoding the polypeptide sequence of SEQ ID NO:1; (b) a DNA sequence comprising SEQ ID NO:2; (c) a nucleic acid sequence that hybridizes to SEQ ID NO:2 under conditions of 1×SSC, and 65° C. and encodes a polypeptide which regulates flavonoid synthesis; (d) a nucleic acid sequence encoding a polypeptide with at least 85% amino acid identity to SEQ ID NO:1, and encodes a polypeptide which regulates flavonoid synthesis; (e) a nucleic acid sequence with at least 85% identity to SEQ ID NO:2 and encodes a polypeptide which regulates flavonoid synthesis;

and (f) a complement of a sequence of (a)-(e), or a fragment thereof, wherein the DNA sequence regulates flavonoid synthesis and is operably linked to a heterologous promoter.

In some embodiments of the invention, the plant further comprises a recombinant vector, wherein the polypeptide that activates anthocyanin or proanthocyanidin biosynthesis is selected from the group consisting of: phenylalanine ammonia-lyase (PAL), cinnamate 4-hydroxylase (C4H), 4-coumarate:CoA ligase (4CL), chalcone synthase (CHS), chalcone isomerase (CHI), flavanone 3-hydroxylase (F3H), dihydroflavonol reductase (DFR), anthocyanidin synthase (ANS), leucoanthocyanidin reductase (LAR), anthocyanidin reductase (ANR), a proanthocyanidin or anthocyanidin glucosyltransferase (GT), LAP1, LAP2, LAP3, LAP4, or AtPAP1 (production of anthocyanin pigment). In certain embodiments, the nucleic acid sequence is introduced into the plant by plant breeding. In other embodiments, the nucleic acid sequence is introduced into the plant by genetic transformation of the plant. Further, in other embodiments the recombinant vector comprises a promoter which is a constitutive or tissue specific promoter. In some embodiments, the plant is further defined as a forage crop. In particular embodiments the plant is a forage legume. In even more particular embodiments the plant is alfalfa.

The invention also provides a method further defined as comprising the preparation of a transgenic progeny plant of any generation of a plant provided herein, wherein the progeny plant comprises the selected nucleic acid sequence. A plant or plant part prepared by this method is also provided.

Yet another aspect of the invention is a method of making food or feed for human or animal consumption comprising: (a) obtaining the plant comprising the DNA molecule; (b) growing the plant under plant growth conditions to produce plant tissue from the plant; and (c) preparing food or feed for human or animal consumption from the plant tissue. In certain embodiments, preparing food or feed comprises harvesting the plant tissue. In some embodiments, the plant tissue is leaf or stem tissue. In particular embodiments, the food or feed is hay, silage, starch, protein, meal, flour or grain.

BRIEF DESCRIPTION OF THE DRAWINGS

The following drawings form part of the present specification and are included to further demonstrate certain aspects of the invention. The invention may be better understood by reference to one or more of these drawings in combination with the detailed description of specific embodiments presented herein:

FIG. 1: (a) Expression profile of MtPAR through seed development (10 to 36 DAP) according to the *Medicago* gene expression atlas and in seed tissues (SC, seed coat; E/Eo, embryo and endosperm) according to qRT-PCR data. (b) Phylogenetic analysis of putative flavonoid regulatory proteins containing a R2R3 MYB domain from different species. Alignment was done using ClustalW algorithm and the tree was generated using NJ method. GeneBank accession numbers of amino acid sequences used to prepare this alignment are provided in Table 1.

FIG. 2: (a) Effect of mutation on mature seed pigmentation for all mutant lines. DMACA staining of mature seeds from all mutant lines. (b) MtPAR transcript levels between WT and mutant lines. Relative expression is given with respect to MSC27 and PDF2 housekeeping genes. (c) Vanillin staining on mature seeds from two mutant lines and their siblings.

FIG. 3: (a) MtPAR gene model with position of different Tnt1 insertions and the names of the corresponding independent mutant lines. Introns are represented using a line and

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exons using a rectangular shape; (b) Effect of mutation on mature seed pigmentation for the NF3308 mutant line. A similar phenotype was observed in other mutant lines; (c) DMACA staining of mature seeds from NF3308 mutant line; (d) Levels of extractable PAs (soluble and insoluble); and (e) anthocyanins with respect to their null segregant controls. Values are mean and standard deviations from three biological replicates.

FIG. 4: HPLC chromatograph of anthocyanidins released by hydrolysis of insoluble PAs in butanol-HCl. (a) HPLC chromatogram of hydrolyzate of procyanidin B1 standard. Cyanidin is released. (b) HPLC chromatogram of hydrolyzate of insoluble PA from MtPAR segregant control *M. truncatula* seeds. (c) HPLC chromatogram of hydrolyzate from insoluble PA from MtPAR mutant seeds.

FIG. 5: Analysis of size distribution of PAs in *Medicago* lines (a-d) and hairy root lines (e-f). For (a-d), soluble PAs were resolved by normal phase HPLC with post-column derivatization DMACA reagent and monitoring at 640 nm. Standards of monomer (epicatechin) (a) and dimer (procyanidin B1) (b). (c) Soluble PAs from *M. truncatula* MtPAR Tnt1 mutant seeds. (d) PAs from *M. truncatula* null segregant control seeds. (e) Soluble PAs from *M. truncatula* hairy roots expressing GUS (control). (f) PAs from *M. truncatula* hairy root lines expressing MtPAR.

FIG. 6: (a) Development of PA accumulation through seed development between mutant and WT lines using DMACA staining. (b) Cross sections of WT and mutant seeds.

FIG. 7: (a) Phenotype of MtPAR ectopic expression transformants in Hairy roots: GFP detection as a transformation marker; Unstained and DMACA-stained hairy roots; (b) Levels of extractable soluble PAs and anthocyanins from hairy roots over-expressing MtPAR or GUS. Values are mean and standard deviations from three biological replicates.

FIG. 8: Insoluble PA content in different hairy roots lines over-expressing MtPAR.

FIG. 9: (a) Venn diagram for genes down-regulated in loss of function par mutants and up-regulated following ectopic expression of MtPAR in hairy roots; (b) Table representing the 11 common genes which are down-regulated in loss of function mutant lines and up-regulated in ectopic expression transformant lines. Affymetrix ID, putative annotation, TC, expression ratio between mutant vs WT or over-expressing lines vs control with their respective p and q-value are indicated. Significant p-value are indicated in grey.

FIG. 10: (a) Schematic representation of the flavonoid biosynthetic pathway leading to PAs and anthocyanins. * represents enzymes for which transcript levels are significantly affected in both mutant lines and over-expressing transformants. PAL, phenylalanine ammonia-lyase; C4H, cinnamate 4-hydroxylase; 4CL, 4-coumarate CoA ligase; CHS, chalcone synthase; CHI, chalcone isomerase; F3H, flavanone 3-hydroxylase; FLS, flavonol synthase; DFR, dihydroflavonol 4-reductase; LAR, leucoanthocyanidin reductase; ANS, anthocyanidin synthase; ANR, anthocyanidin reductase; OMT, o-methyltransferase; UFGT, UDP flavonoid glucosyl transferase; RT, rhamnosyl transferase; GT, glucosyl transferase; TT2, transparent testa2; TT8, transparent testa8; TTG1, transparent testa glabral. (b) Cumulative expression values of different probesets encoding putative genes involved in flavonoid biosynthesis. Averages of the three biological replicates are indicated with their respective SD. PAL gene expression is constituted by cumulative expression of 8 different probesets encoding for putative PAL enzyme; 4CL by 17 probesets; CHS, 31 probesets; CHI, 10 probesets; F3H, 12 probesets; FLS, 3 probesets; DFR, 4 probesets; JAR, 1 probeset; ANS, 3 probesets; ANR, 2

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probesets; GT, 6 probesets; TT2-like, 1 probeset; TT8-like, 2 probesets; TTG1-like, 2 probesets. Different probeset IDs for each gene are indicated in supplementary material S6. Expression values for WT were normalized against respective control lines and adjusted to 1. (c) Statistically significant changes in flavonoid content in par mutants with respect to their segregant WT lines. All other flavonoid content changes are indicated in Table 5. Averages of the three biological replicates are indicated with their respective SD.

FIG. 11: (a) Venn diagram for genes affected in par and ttg1 mutants in *M. truncatula*. A complete list of common probesets down-regulated in par and ttg1 mutant lines is given in Table 6. (b) Transcript levels of MtWD40-1 in different par lines and in hairy roots transformants. Relative expression was calculated from qRT-PCR data with respect to transcript levels of two housekeeping genes MSC27 and PDF2. (c) Venn diagram for genes affected by over-expression of MtPAR and AtTT2 in *M. truncatula* hairy roots. A complete list of common probesets up-regulated in hairy root transformants over-expressing PAR and TT2 is given in Table 7.

DETAILED DESCRIPTION OF THE INVENTION

The invention provides methods and compositions for the modification of proanthocyanidin (PA) metabolism in plants. In one embodiment, a MYB family transcription factor ("TF") was identified that regulates PA biosynthesis in seeds. Ectopic expression of the gene in transformed hairy-roots surprisingly led to PA biosynthesis and accumulation. The sequence was identified as a MYB transcription factor and designated as *Medicago truncatula* ProAnthocyanidin Regulator (MtPAR). In accordance with the invention MtPAR will find use in, for example, increasing tannin levels for forage improvement in plants including legumes such as *Medicago* spp. The sequence of the predicted MtPAR polypeptide is given in SEQ ID NO:1 and the mRNA gene sequence is given in SEQ ID NO:2. The genomic MtPAR gene sequence is given in SEQ ID NO:3. This seed coat specific gene acts as a positive regulator of PA biosynthesis.

Importantly, transcription profiling and other studies showed that MtPAR regulates expression of a distinct set of genes, including genes involved in flavonoid biosynthesis, relative to other MYB TFs, such as tt2 and ttg1. For instance, the inventors show herein that heterologous expression of MtPAR affects expression of CHS, F3H, ANS, and AHR enzymes, among tested-for activities. The effects of MtPAR over-expression (or under-expression) on proanthocyanidin accumulation as well as on gene expression profiles in *Medicago* could thus not have been predicted based on studies of effects of other known MYB TFs from *Medicago Glycine*, or *Arabidopsis*.

Transcriptional regulation of flavonoid biosynthesis is not yet well understood in legumes. In the non-legume *Arabidopsis*, six loci are known to have regulatory functions in PA biosynthesis, TT1, TT2, TT8, TT16, TTG1 and TTG2 (for review, see Lepiniec et al., 2006). TT1 and TT16 encode a zinc finger and a MADS box protein, respectively, and are essential for seed pigmentation (Nesi et al., 2002; Sagasser et al., 2002). TTG2 encodes a WRKY transcription factor, which acts downstream of TTG1 (Johnson et al., 2002). TT2, TT8 and TTG1 encode a MYB (Nesi et al., 2001), a bHLH (Nesi et al., 2000) and a WD40 protein (Walker et al., 1999), respectively, which interact to form a ternary TF complex. Mutation in any one of these TFs affects both anthocyanin and PA content in seeds via down-regulation of flavonoid biosynthetic genes (for review Debeaujon et al., 2007). In the *Medicago* par mutants, down-regulation of key genes of the fla-

vonoid pathway was observed. However, in contrast to the *Arabidopsis* mutants, mutations in MtPAR affect soluble and insoluble PA content but not anthocyanin content (FIG. 2b, 2e).

MtPAR plays a specific role in the regulation of PA biosynthesis in *Medicago* seeds. First, MtPAR1 gene expression was confined to the seed coat, the site of PA accumulation in developing seed (FIG. 1). Second, loss-of-function (Tnt1-insertion) par mutants accumulated substantially less PA in the seed coat than did wild-type controls (FIG. 2). Third, anthocyanin levels remained normal in par mutant seed (FIG. 2) despite the existence of a common pathway that generates precursors for PA and anthocyanin biosynthesis (see FIG. 5). Fourth, no aberrant phenotype apart from pale seed color was evident in any organ of par mutants. Fifth, ectopic over-expression of MtPAR1 in roots led to production of PA in an organ that normally does not accumulate PAs (FIG. 3). Sixth, genes that exhibited decreased expression (relative to wild-type) in the seed of par mutants and were expressed at a higher level in MtPAR over-expressing roots are largely involved in flavonoid and PA biosynthesis (FIGS. 4-5). These putative target genes of MtPAR protein activity include three CHS, two F3H, and the ANS genes, which are required for both PA and anthocyanin production, as well as the ANR gene, which is required for PA production alone (FIG. 4b, FIG. 5).

It was surprising that anthocyanin levels were unaffected while PA levels were substantially reduced in par mutant seed compared to the wild-type, given that many of the genes required for both PA and anthocyanin biosynthesis showed decreased expression in the mutant. Without being bound to any given theory, it may be that metabolic channeling explains these results. For example, if ANS and ANR were physically-coupled, the product of ANS activity, 3-OH-anthocyanidin, would be converted preferentially to epicatechin (and ultimately PA) by ANR, rather than being glycosylated for anthocyanin production (FIG. 5). In addition to the decrease in PA levels, an increase in flavonol glycosides was noted in par mutants (FIG. 5c), which coincided with an increase of 31.8% in transcript levels of FLS genes. FLS genes may be regulated directly (negatively) by MtPAR, or regulation may be indirect, via a change in flavonoid pathway activity or metabolite levels for instance. Flavonoid content changes are indicated for instance in Table 7.

Some of the key genes/enzymes involved in *M. truncatula* PA biosynthesis have been characterized, including ANR, ANS and LAR (Xie et al., 2004; Pang et al., 2007). However, little is known about regulation of PA biosynthetic genes in *Medicago*. A single WD40-repeat TF, MtWD-40-1, orthologous to *Arabidopsis* AtTTG1, was identified as a positive regulator of PA biosynthesis in *M. truncatula* seeds (Pang et al., 2009). The action of MtWD-40-1 was compared with that of MtPAR in *M. truncatula* (e.g. see FIG. 6), and it appears that both genes may belong to the same regulatory network. For instance, both mutants exhibit a substantial decrease of PA levels in seed (FIG. 2d; Pang et al., 2009). Furthermore, transcriptomic analysis revealed that a common set of genes was down-regulated in mutants defective in these genes. Gene expression analysis also revealed a decrease of MtWD40-1 gene expression in par mutant lines (FIG. 6c), suggesting that MtPAR regulates MtWD40-1 expression. The converse was not the case, as MtPAR expression was not affected in wd40-1 mutants (Pang et al., 2009). This may explain why ectopic expression of MtPAR, but not of MtWD-40-1, resulted in PA biosynthesis in roots (FIG. 3). If a complex of TFs, including MtPAR and MtWD-40-1 is required to induce flavonoid biosynthesis genes, as is the case in *Arabidopsis* (Baudry et al., 2004), then ectopic expression of

MtPAR, and consequent induction of MtWD-40-1 may have provided the requisite TFs for PA biosynthesis in roots. In contrast, ectopic expression of MtWD-40-1 would not induce MtPAR expression and would, therefore, fail to induce PA biosynthesis.

Many forage crops are low in PA, including *Medicago* spp. such as alfalfa and annual medics, white clover, ball clover, Persian clover, red clover, crimson clover, berseem clover, arrowleaf clover, alsike clover, subterranean clovers, fenugreek, and sweetclover (*Melilotus* spp.). Consumption of forage tissues low in PA can lead to "bloat." Similarly, bloat can be caused by grazing of wheat pastures and other lush foliage, such as fast-growing monocots. "Feedlot bloat" also occurs in cattle fed high-grain rations that may or may not contain legume forage, green-chopped legumes, or other finely ground feed. In these cases, direct engineering of PA accumulation in the forage plant may be used in accordance with the invention to prevent bloat. Further, PA modification could be engineered into feed components that are blended or added to bloat-causing components to reduce the bloat incidence in animals consuming the mixed feed. Specifically contemplated by the invention, is therefore the modification of any species that may be used in feed provided to animals, including monocot species such as corn, wheat, sorghum, and various grasses, among others.

One application of the invention is the modification of PA biosynthesis in plants with low PA content. Alfalfa is one such plant. Proanthocyanidins are made in alfalfa (*Medicago sativa*), as in *Arabidopsis*, in the seed coat, but do not accumulate in the leaves (Koupai-Abyazani et al., 1993; Skadhauge et al., 1997). Nonetheless, alfalfa is the world's major forage legume. Therefore, enhancing PA biosynthesis for instance in the leaves or other tissues of alfalfa or other low PA plants would substantially improve the utility of this crop for feed by reduction of its potential for causing pasture bloat. Forage crops that accumulate PAs in leaves have low bloating potential; these include *Lotus corniculatus*, *Leucaena leucocephala*, *Hedysarum sulfurescens* and *Robinia* spp.

Technology that could result in constitutive expression of PAs in high protein forage crops would also greatly improve the agronomic value of crops in addition to alfalfa. In addition, the potential importance of PAs in human health makes methods for their facile production in plants necessary for the full development of their therapeutic potential.

The present invention provides methods and compositions for increasing PAs comprising introducing transgenic MtPAR coding sequences. In certain aspects, this may be provided in combination with another coding sequence which functions to enhance PA biosynthesis in a plant.

I. Application of the Invention

As indicated above, one application of the invention is the introduction or increase of PA biosynthesis in plants. Such applications may result in forage improvement and nutritional improvement of foods. In accordance with the invention this may be carried out by introduction of MtPAR alone or in combination with other PA biosynthesis genes, regulatory or structural, such as described herein. The invention may thus be used to improve the nutritional quality of plants. Catechins and similar flavonoids have been reported to behave as strong antioxidants and have other properties which may make their consumption beneficial to human and animal health. Also, such compounds are generally antimicrobial, and their presence may improve food quality by

preventing pre- and post-harvest damage. Accordingly, increases in PA biosynthesis may be used to achieve the associated health benefits.

In addition to providing the MtPAR gene alone, other genes may be used to enhance the accumulation of condensed tannins, especially in combination with MtWD40-1, ANS, ANR, or BAN/LAR expression. For example, MtPAR may be provided with MtWD40-1 (Pang et al., 2009; GenBank accession EU040206; SEQ ID NO:4). These sequences may find use with the invention as is described herein.

As indicated above, a modulation of the phenotype of a gene may be obtained in accordance with the invention by introduction of recombinant nucleic acids comprising a MtPAR coding sequence. Such a nucleic acid may be in the sense and/or antisense orientation. Also provided by the invention are MtPAR sequences that hybridize to the coding sequences provided herein under high stringency conditions. As used herein, "hybridization" or "hybridizes" is understood to mean the forming of a double or triple stranded molecule or a molecule with partial double or triple stranded nature. As used herein "stringent condition(s)" or "high stringency" are those conditions that allow hybridization between or within one or more nucleic acid strand(s) containing complementary sequence(s), but precludes hybridization of random sequences.

Stringent conditions tolerate little mismatch between a nucleic acid and a target strand. Such conditions are well known to those of ordinary skill in the art, and are preferred for applications requiring high selectivity. Medium stringent conditions may comprise relatively low salt and/or relatively high temperature conditions, such as provided by about 5×SSC, 50% formamide and 42° C.; or alternatively, 5×SSC, 50% formamide and 55° C. High stringency may be defined as 0.02M to 0.10M NaCl and 50° C. to 70° C. Specific examples of such conditions include 0.02M NaCl and 50° C.; 0.02M NaCl and 60° C.; and 0.02M NaCl and 70° C. Other examples of such conditions are 1×SSC, and 65° C.; or 0.2×-0.5×SSC and 65° C.

It is understood that the temperature and ionic strength of a desired stringency are determined in part by the length of the particular nucleic acid(s), the length and nucleobase content of the target sequence(s), the charge composition of the nucleic acid(s), and to the presence or concentration of formamide, tetramethylammonium chloride or other solvent(s) in a hybridization mixture. It is also understood that compositions and conditions for hybridization are mentioned by way of non-limiting examples only, and that the desired stringency for a particular hybridization reaction in a plant cell is often determined empirically by comparison to one or more positive or negative controls. Depending on the application envisioned it is preferred to employ varying conditions of hybridization to achieve varying degrees of selectivity of a nucleic acid towards a target sequence.

II. Plant Transformation Constructs

Certain embodiments of the current invention concern plant transformation constructs. For example, one aspect of the current invention is a plant transformation vector comprising a MtPAR coding sequence alone or in combination with one or more other flavonoid or PA biosynthesis gene(s). Examples of PA biosynthesis genes include BAN, PAP-1, TTG1 TTG2, TT1, and/or TT8 among others. Exemplary coding sequences of such genes for use with the invention are well known in the art.

In certain embodiments of the invention, coding sequences are provided operably linked to a heterologous promoter, in

either sense or antisense orientation. Expression constructs are also provided comprising these sequences, as are plants and plant cells transformed with the sequences.

The construction of vectors which may be employed in conjunction with plant transformation techniques using these or other sequences according to the invention will be known to those of skill of the art in light of the present disclosure (see, for example, Sambrook et al., 1989; Gelvin et al., 1990). The techniques of the current invention are thus not limited to any particular nucleic acid sequences.

One beneficial use of the sequences provided by the invention will be in the alteration of plant phenotypes by genetic transformation with sense or antisense PA biosynthesis genes. The PA biosynthesis gene such as MtPAR may be provided with other sequences. Where an expressible coding region that is not necessarily a marker coding region is employed in combination with a marker coding region, one may employ the separate coding regions on either the same or different DNA segments for transformation. In the latter case, the different vectors are delivered concurrently to recipient cells to maximize cotransformation.

The choice of any additional elements used in conjunction with the PA biosynthesis coding sequences will often depend on the purpose of the transformation. One of the major purposes of transformation of crop plants is to add commercially desirable, agronomically important traits to the plant. As PAs are known to confer many beneficial effects on health, one such trait is increased biosynthesis of tannins. Alternatively, plants may be engineered to decrease synthesis of PA.

Vectors used for plant transformation may include, for example, plasmids, cosmids, YACs (yeast artificial chromosomes), BACs (bacterial artificial chromosomes) or any other suitable cloning system, as well as fragments of DNA therefrom. Thus when the term "vector" or "expression vector" is used, all of the foregoing types of vectors, as well as nucleic acid sequences isolated therefrom, are included. It is contemplated that utilization of cloning systems with large insert capacities will allow introduction of large DNA sequences comprising more than one selected gene. In accordance with the invention, this could be used to introduce genes corresponding to the entire PA biosynthetic pathway into a plant. Introduction of such sequences may be facilitated by use of bacterial or yeast artificial chromosomes (BACs or YACs, respectively), or even plant artificial chromosomes. For example, the use of BACs for *Agrobacterium*-mediated transformation was disclosed by Hamilton et al., (1996).

Particularly useful for transformation are expression cassettes which have been isolated from such vectors. DNA segments used for transforming plant cells will, of course, generally comprise the cDNA, gene or genes which one desires to introduce into and have expressed in the host cells. These DNA segments can further include structures such as promoters, enhancers, polylinkers, or even regulatory genes as desired. The DNA segment or gene chosen for cellular introduction will often encode a protein which will be expressed in the resultant recombinant cells resulting in a screenable or selectable trait and/or which will impart an improved phenotype to the resulting transgenic plant. However, this may not always be the case, and the present invention also encompasses transgenic plants incorporating non-expressed transgenes. Preferred components likely to be included with vectors used in the current invention are as follows.

A. Regulatory Elements

Exemplary promoters for expression of a nucleic acid sequence include plant promoter such as the CaMV 35S promoter (Odell et al., 1985), or others such as CaMV 19S

(Lawton et al., 1987), nos (Ebert et al., 1987), Adh (Walker et al., 1987), sucrose synthase (Yang and Russell, 1990), a-tubulin, actin (Wang et al., 1992), cab (Sullivan et al., 1989), PEPCase (Hudspeth and Grula, 1989) or those associated with the R gene complex (Chandler et al., 1989). Tissue specific promoters such as root cell promoters (Conkling et al., 1990) and tissue specific enhancers (Fromm et al., 1986) are also contemplated to be particularly useful, as are inducible promoters such as ABA- and turgor-inducible promoters. In one embodiment of the invention, the native promoter of a PA biosynthesis gene is used.

The DNA sequence between the transcription initiation site and the start of the coding sequence, i.e., the untranslated leader sequence, can also influence gene expression. One may thus wish to employ a particular leader sequence with a transformation construct of the invention. Preferred leader sequences are contemplated to include those which comprise sequences predicted to direct optimum expression of the attached gene, i.e., to include a preferred consensus leader sequence which may increase or maintain mRNA stability and prevent inappropriate initiation of translation. The choice of such sequences will be known to those of skill in the art in light of the present disclosure. Sequences that are derived from genes that are highly expressed in plants will typically be preferred.

It is specifically envisioned that PA biosynthesis coding sequences may be introduced under the control of novel promoters or enhancers, etc., or homologous or tissue specific promoters or control elements. Vectors for use in tissue-specific targeting of genes in transgenic plants will typically include tissue-specific promoters and may also include other tissue-specific control elements such as enhancer sequences. Promoters which direct specific or enhanced expression in certain plant tissues will be known to those of skill in the art in light of the present disclosure. These include, for example, the *rbcS* promoter, specific for green tissue; the *ocs*, *nos* and *mas* promoters which have higher activity in roots or wounded leaf tissue; a truncated (−90 to +8) 35S promoter which directs enhanced expression in roots, and an α -tubulin gene that also directs expression in roots.

B. Terminators

Transformation constructs prepared in accordance with the invention will typically include a 3' end DNA sequence that acts as a signal to terminate transcription and allow for the poly-adenylation of the mRNA produced by coding sequences operably linked to a PA biosynthesis gene. In one embodiment of the invention, the native terminator of a PA biosynthesis gene is used. Alternatively, a heterologous 3' end may enhance the expression of sense or antisense PA biosynthesis genes. Terminators which are deemed to be particularly useful in this context include those from the nopaline synthase gene of *Agrobacterium tumefaciens* (nos 3' end) (Bevan et al., 1983), the terminator for the T7 transcript from the octopine synthase gene of *Agrobacterium tumefaciens*, and the 3' end of the protease inhibitor I or II genes from potato or tomato. Regulatory elements such as an Adh intron (Callis et al., 1987), sucrose synthase intron (Vasil et al., 1989) or TMV omega element (Gallie et al., 1989), may further be included where desired.

C. Transit or Signal Peptides

Sequences that are joined to the coding sequence of an expressed gene, which are removed post-translationally from the initial translation product and which facilitate the transport of the protein into or through intracellular or extracellular membranes, are termed transit (usually into vacuoles, vesicles, plastids and other intracellular organelles) and signal sequences (usually to the endoplasmic reticulum, golgi

apparatus and outside of the cellular membrane). By facilitating the transport of the protein into compartments inside and outside the cell, these sequences may increase the accumulation of gene product protecting them from proteolytic degradation. These sequences also allow for additional mRNA sequences from highly expressed genes to be attached to the coding sequence of the genes. Since mRNA being translated by ribosomes is more stable than naked mRNA, the presence of translatable mRNA in front of the gene may increase the overall stability of the mRNA transcript from the gene and thereby increase synthesis of the gene product. Since transit and signal sequences are usually post-translationally removed from the initial translation product, the use of these sequences allows for the addition of extra translated sequences that may not appear on the final polypeptide. It further is contemplated that targeting of certain proteins may be desirable in order to enhance the stability of the protein (U.S. Pat. No. 5,545,818, incorporated herein by reference in its entirety).

Additionally, vectors may be constructed and employed in the intracellular targeting of a specific gene product within the cells of a transgenic plant or in directing a protein to the extracellular environment. This generally will be achieved by joining a DNA sequence encoding a transit or signal peptide sequence to the coding sequence of a particular gene. The resultant transit, or signal, peptide will transport the protein to a particular intracellular, or extracellular destination, respectively, and will then be post-translationally removed.

D. Marker Genes

By employing a selectable or screenable marker protein, one can provide or enhance the ability to identify transformants. "Marker genes" are genes that impart a distinct phenotype to cells expressing the marker protein and thus allow such transformed cells to be distinguished from cells that do not have the marker. Such genes may encode either a selectable or screenable marker, depending on whether the marker confers a trait which one can "select" for by chemical means, i.e., through the use of a selective agent (e.g., a herbicide, antibiotic, or the like), or whether it is simply a trait that one can identify through observation or testing, i.e., by "screening" (e.g., the green fluorescent protein). Of course, many examples of suitable marker proteins are known to the art and can be employed in the practice of the invention.

Included within the terms selectable or screenable markers also are genes which encode a "secretable marker" whose secretion can be detected as a means of identifying or selecting for transformed cells. Examples include markers which are secretable antigens that can be identified by antibody interaction, or even secretable enzymes which can be detected by their catalytic activity. Secretable proteins fall into a number of classes, including small, diffusible proteins detectable, e.g., by ELISA; small active enzymes detectable in extracellular solution (e.g., α -amylase, β -lactamase, phosphinothricin acetyltransferase); and proteins that are inserted or trapped in the cell wall (e.g., proteins that include a leader sequence such as that found in the expression unit of extensin or tobacco PR-S).

Many selectable marker coding regions are known and could be used with the present invention including, but not limited to, neo (Potrykus et al., 1985), which provides kanamycin resistance and can be selected for using kanamycin, G418, paromomycin, etc.; bar, which confers bialaphos or phosphinothricin resistance; a mutant EPSP synthase protein (Hinchee et al., 1988) conferring glyphosate resistance; other such selectable marker coding regions are well known in the art.

III. Antisense and RNAi Constructs

Antisense and RNAi treatments represent one way of altering PA biosynthesis in accordance with the invention. In particular, constructs comprising a PA biosynthesis gene and/or a promoter thereof in antisense orientation may be used to decrease or effectively eliminate the expression of PA in a plant. Accordingly, this may alternatively be used to increase anthocyanin accumulation in a plant or given plant tissue. As such, antisense technology may be used to “knock-out” the function of a PA biosynthesis gene or homologous sequences thereof.

Antisense methodology takes advantage of the fact that nucleic acids tend to pair with “complementary” sequences. By complementary, it is meant that polynucleotides are those which are capable of base-pairing according to the standard Watson-Crick complementarity rules. That is, the larger purines will base pair with the smaller pyrimidines to form combinations of guanine paired with cytosine (G:C) and adenine paired with either thymine (A:T) in the case of DNA, or adenine paired with uracil (A:U) in the case of RNA. Inclusion of less common bases such as inosine, 5-methylcytosine, 6-methyladenine, hypoxanthine and others in hybridizing sequences does not interfere with pairing.

RNA interference (RNAi) is a process utilizing endogenous cellular pathways whereby a double stranded RNA (dsRNA) specific target gene results in the degradation of the mRNA of interest. In recent years, RNAi has been used to perform gene “knockdown” in a number of species and experimental systems, from the nematode *C. elegans*, to plants, to insect embryos and cells in tissue culture (Fire et al., 1998; Martinez et al., 2002; McManus and Sharp, 2002). RNAi works through an endogenous pathway including the Dicer protein complex that generates ~21-nucleotide small interfering RNAs (siRNAs) from the original dsRNA and the RNA-induced silencing complex (RISC) that uses siRNA guides to recognize and degrade the corresponding mRNAs. Only transcripts complementary to the siRNA are cleaved and degraded, and thus the knock-down of mRNA expression is usually sequence specific. One of skill in the art would routinely be able to identify portions of, for instance, MIPAR sequence, as targets for RNAi-mediated gene suppression.

Targeting double-stranded (ds) DNA with polynucleotides may lead to triple-helix formation; targeting RNA will lead to double-helix formation. Antisense polynucleotides, when introduced into a target cell, specifically bind to their target polynucleotide and interfere with transcription, RNA processing, transport, translation and/or stability. Antisense RNA constructs, or DNA encoding such antisense RNA's, may be employed to inhibit gene transcription or translation or both within a host cell.

Antisense or RNAi constructs may be targeted to promoter and other control regions, exons, introns or even exon-intron boundaries of a gene. It is contemplated that the certain effective constructs will include regions complementary to intron/exon splice junctions. Thus, one example of a construct may comprise complementarity to regions within 50-200 bases of an intron-exon splice junction. It has been observed that some exon sequences can be included in the construct without seriously affecting the target selectivity thereof. The amount of exonic material included will vary depending on the particular exon and intron sequences used. One can readily test whether too much exon DNA is included simply by testing the constructs in vitro to determine whether normal cellular function is affected or whether the expression of related genes having complementary sequences is affected.

As stated above, “complementary” or “antisense” means polynucleotide sequences that are substantially complementary over their entire length and have very few base mismatches. For example, sequences of fifteen bases in length may be termed complementary when they have complementary nucleotides at thirteen or fourteen positions. Naturally, sequences which are completely complementary will be sequences which are entirely complementary throughout their entire length and have no base mismatches. Other sequences with lower degrees of homology also are contemplated. For example, an antisense construct which has limited regions of high homology, but also contains a non-homologous region (e.g., ribozyme; see above) could be designed. These molecules, though having less than 50% homology, would bind to target sequences under appropriate conditions.

It may be advantageous to combine portions of genomic DNA with cDNA or synthetic sequences to generate specific constructs. For example, where an intron is desired in the ultimate construct, a genomic clone will need to be used. The cDNA or a synthesized polynucleotide may provide more convenient restriction sites for the remaining portion of the construct and, therefore, would be used for the rest of the sequence.

IV. Tissue Cultures

Tissue cultures may be used in certain transformation techniques for the preparation of cells for transformation and for the regeneration of plants therefrom. Maintenance of tissue cultures requires use of media and controlled environments. “Media” refers to the numerous nutrient mixtures that are used to grow cells in vitro, that is, outside of the intact living organism. The medium usually is a suspension of various categories of ingredients (salts, amino acids, growth regulators, sugars, buffers) that are required for growth of most cell types.

Methods for plant cell culture, including preparing and using nutrient media, such as a liquid medium or a solid medium, are well known in the art. Manual selection of recipient cells, e.g., by selecting embryogenic cells from the surface of a callus, is one means that may be used in an attempt to enrich for particular cells prior to culturing (whether cultured on solid media or in suspension). Where employed, cultured cells may be grown either on solid supports or in the form of liquid suspensions. In either instance, nutrients may be provided to the cells in the form of media, and environmental conditions controlled. There are many types of tissue culture media comprised of various amino acids, salts, sugars, growth regulators and vitamins. Most of the media employed in the practice of the invention will have some similar components, but may differ in the composition and proportions of their ingredients depending on the particular application envisioned. Various types of media suitable for culture of plant cells previously have been described. Examples of these media include, but are not limited to, the N6 medium described by Chu et al., (1975) and MS media (Murashige and Skoog, 1962).

V. Methods for Genetic Transformation

Suitable methods for transformation of plant or other cells for use with the current invention are well known, and are believed to include virtually any method by which DNA can be introduced into a cell, such as by *Agrobacterium*-mediated transformation (U.S. Pat. No. 5,591,616 and U.S. Pat. No. 5,563,055; both specifically incorporated herein by reference) and by acceleration of DNA coated particles. Through

the application of techniques such as these, the cells of virtually any plant species may be stably transformed, and these cells developed into transgenic plants. In those plant strains where *Agrobacterium*-mediated transformation is efficient, it is often the method of choice because of the facile and defined nature of the gene transfer.

VI. Production and Characterization of Stably Transformed Plants

After effecting delivery of exogenous DNA to recipient cells, the next steps generally concern identifying the transformed cells for further culturing and plant regeneration. In order to improve the ability to identify transformants, one may desire to employ a selectable or screenable marker gene with a transformation vector prepared in accordance with the invention. In this case, one would then generally assay the potentially transformed cell population by exposing the cells to a selective agent or agents, or one would screen the cells for the desired marker gene trait.

It is contemplated that using the techniques of dot or slot blot hybridization which are modifications of Southern hybridization techniques one could obtain the same information that is derived from PCRTM, e.g., the presence of a gene. Both PCRTM and Southern hybridization techniques can be used to demonstrate transmission of a transgene to progeny. In most instances the characteristic Southern hybridization pattern for a given transformant will segregate in progeny as one or more Mendelian genes (Spencer et al., 1992) indicating stable inheritance of the transgene.

Whereas DNA analysis techniques may be conducted using DNA isolated from any part of a plant, RNA will only be expressed in particular cells or tissue types and hence it will be necessary to prepare RNA for analysis from these tissues. PCRTM techniques also may be used for detection and quantitation of RNA produced from introduced genes. In this application of PCRTM it is first necessary to reverse transcribe RNA into DNA, using enzymes such as reverse transcriptase, and then through the use of conventional PCRTM techniques amplify the DNA. In most instances PCRTM techniques, while useful, will not demonstrate integrity of the RNA product. Further information about the nature of the RNA product may be obtained by Northern blotting. This technique will demonstrate the presence of an RNA species and give information about the integrity of that RNA. The presence or absence of an RNA species also can be determined using dot or slot blot Northern hybridizations. These techniques are modifications of Northern blotting and will only demonstrate the presence or absence of an RNA species.

While Southern blotting and PCRTM may be used to detect the gene(s) in question, they do not provide information as to whether the corresponding protein is being expressed. Expression may be evaluated by specifically identifying the protein products of the introduced genes or evaluating the phenotypic changes brought about by their expression.

Assays for the production and identification of specific proteins may make use of physical-chemical, structural, functional, or other properties of the proteins. Unique physical-chemical or structural properties allow the proteins to be separated and identified by electrophoretic procedures, such as native or denaturing gel electrophoresis or isoelectric focusing, or by chromatographic techniques such as ion exchange or gel exclusion chromatography. The unique structures of individual proteins offer opportunities for use of specific antibodies to detect their presence in formats such as an ELISA assay. Combinations of approaches may be employed with even greater specificity such as western blot-

ting in which antibodies are used to locate individual gene products that have been separated by electrophoretic techniques. Additional techniques may be employed to absolutely confirm the identity of the product of interest such as evaluation by amino acid sequencing following purification. Although these are among the most commonly employed, other procedures may be additionally used.

Assay procedures also may be used to identify the expression of proteins by their functionality, especially the ability of enzymes to catalyze specific chemical reactions involving specific substrates and products. These reactions may be followed by providing and quantifying the loss of substrates or the generation of products of the reactions by physical or chemical procedures. Examples are as varied as the enzyme to be analyzed and may include assays for PAT enzymatic activity by following production of radiolabeled acetylated phosphinothricin from phosphinothricin and ¹⁴C-acetyl CoA or for anthranilate synthase activity by following loss of fluorescence of anthranilate, to name two.

Very frequently the expression of a gene product is determined by evaluating the phenotypic results of its expression. These assays also may take many forms including but not limited to analyzing changes in the chemical composition, morphology, or physiological properties of the plant. Chemical composition may be altered by expression of genes encoding enzymes or storage proteins which change amino acid composition and may be detected by amino acid analysis, or by enzymes which change starch quantity which may be analyzed by near infrared reflectance spectrometry. Morphological changes may include greater stature or thicker stalks. Most often changes in response of plants or plant parts to imposed treatments are evaluated under carefully controlled conditions termed bioassays.

VII. Breeding Plants of the Invention

In addition to direct transformation of a particular plant genotype with a construct prepared according to the current invention, transgenic plants may be made by crossing a plant having a selected DNA of the invention to a second plant lacking the construct. For example, a selected PA biosynthesis gene can be introduced into a particular plant variety by crossing, without the need for ever directly transforming a plant of that given variety. Therefore, the current invention not only encompasses a plant directly transformed or regenerated from cells which have been transformed in accordance with the current invention, but also the progeny of such plants. As used herein the term "progeny" denotes the offspring of any generation of a parent plant prepared in accordance with the instant invention, wherein the progeny comprises a selected DNA construct prepared in accordance with the invention. "Crossing" a plant to provide a plant line having one or more added transgenes relative to a starting plant line, as disclosed herein, is defined as the techniques that result in a transgene of the invention being introduced into a plant line by crossing a starting line with a donor plant line that comprises a transgene of the invention. To achieve this one could, for example, perform the following steps:

- (a) plant seeds of the first (starting line) and second (donor plant line that comprises a transgene of the invention) parent plants;
- (b) grow the seeds of the first and second parent plants into plants that bear flowers;
- (c) pollinate a flower from the first parent plant with pollen from the second parent plant; and
- (d) harvest seeds produced on the parent plant bearing the fertilized flower.

Backcrossing is herein defined as the process including the steps of:

(a) crossing a plant of a first genotype containing a desired gene, DNA sequence or element to a plant of a second genotype lacking the desired gene, DNA sequence or element;

(b) selecting one or more progeny plant containing the desired gene, DNA sequence or element;

(c) crossing the progeny plant to a plant of the second genotype; and

(d) repeating steps (b) and (c) for the purpose of transferring a desired DNA sequence from a plant of a first genotype to a plant of a second genotype.

Introgression of a DNA element into a plant genotype is defined as the result of the process of backcross conversion. A plant genotype into which a DNA sequence has been introgressed may be referred to as a backcross converted genotype, line, inbred, or hybrid. Similarly a plant genotype lacking the desired DNA sequence may be referred to as an unconverted genotype, line, inbred, or hybrid.

VIII. Definitions

Proanthocyanidin (PA) biosynthesis gene: A gene encoding a polypeptide that catalyzes one or more steps in the biosynthesis of proanthocyanidins (condensed tannins), or regulates expression or activity of such a gene.

Expression: The combination of intracellular processes, including transcription and translation undergone by a coding DNA molecule such as a structural gene to produce a polypeptide.

Genetic Transformation: A process of introducing a DNA sequence or construct (e.g., a vector or expression cassette) into a cell or protoplast in which that exogenous DNA is incorporated into a chromosome or is capable of autonomous replication.

Heterologous: A sequence which is not normally present in a given host genome in the genetic context in which the sequence is currently found. In this respect, the sequence may be native to the host genome, but be rearranged with respect to other genetic sequences within the host sequence. For example, a regulatory sequence may be heterologous in that it is linked to a different coding sequence relative to the native regulatory sequence.

Obtaining: When used in conjunction with a transgenic plant cell or transgenic plant, obtaining means either transforming a non-transgenic plant cell or plant to create the transgenic plant cell or plant, or planting transgenic plant seed to produce the transgenic plant cell or plant. Such a transgenic plant seed may be from an R_0 transgenic plant or may be from a progeny of any generation thereof that inherits a given transgenic sequence from a starting transgenic parent plant.

Promoter: A recognition site on a DNA sequence or group of DNA sequences that provides an expression control element for a structural gene and to which RNA polymerase specifically binds and initiates RNA synthesis (transcription) of that gene.

R_0 transgenic plant: A plant that has been genetically transformed or has been regenerated from a plant cell or cells that have been genetically transformed.

Regeneration: The process of growing a plant from a plant cell (e.g., plant protoplast, callus or explant).

Selected DNA: A DNA segment which one desires to introduce into a plant genome by genetic transformation.

Transformation construct: A chimeric DNA molecule which is designed for introduction into a host genome by genetic transformation. Preferred transformation constructs will comprise all of the genetic elements necessary to direct

the expression of one or more exogenous genes. In particular embodiments of the instant invention, it may be desirable to introduce a transformation construct into a host cell in the form of an expression cassette.

Transformed cell: A cell the DNA complement of which has been altered by the introduction of an exogenous DNA molecule into that cell.

Transgene: A segment of DNA which has been incorporated into a host genome or is capable of autonomous replication in a host cell and is capable of causing the expression of one or more coding sequences. Exemplary transgenes will provide the host cell, or plants regenerated therefrom, with a novel phenotype relative to the corresponding non-transformed cell or plant. Transgenes may be directly introduced into a plant by genetic transformation, or may be inherited from a plant of any previous generation which was transformed with the DNA segment.

Transgenic plant: A plant or progeny plant of any subsequent generation derived therefrom, wherein the DNA of the plant or progeny thereof contains an introduced exogenous DNA segment not naturally present in a non-transgenic plant of the same strain. The transgenic plant may additionally contain sequences which are native to the plant being transformed, but wherein the "exogenous" gene has been altered in order to alter the level or pattern of expression of the gene, for example, by use of one or more heterologous regulatory or other elements.

Vector: A DNA molecule capable of replication in a host cell and/or to which another DNA segment can be operatively linked so as to bring about replication of the attached segment. A plasmid is an exemplary vector.

IX. Examples

The following examples are included to demonstrate preferred embodiments of the invention. It should be appreciated by those of skill in the art that the techniques disclosed in the examples which follow represent techniques discovered by the inventors to function well in the practice of the invention, and thus can be considered to constitute preferred modes for its practice. However, those of skill in the art should, in light of the present disclosure, appreciate that many changes can be made in the specific embodiments which are disclosed and still obtain a like or similar result without departing from the concept, spirit and scope of the invention. More specifically, it will be apparent that certain agents which are both chemically and physiologically related may be substituted for the agents described herein while the same or similar results would be achieved. All such similar substitutes and modifications apparent to those skilled in the art are deemed to be within the spirit, scope and concept of the invention as defined by the appended claims.

Example 1

MtPAR Encodes a MYB Transcription Factor with Seed Coat-Specific Expression

The *M. truncatula* Gene Expression Atlas ("MtGEA") was used to select seed-induced transcription factor ("TF") genes for genetic characterization. The MtPAR gene was identified by its seed-specific expression profile (probeset ID Mtr.50541.1.S1_at), using the *Medicago truncatula* Gene Expression Atlas webserver (www.mtgea.noble.org; Benedito et al., 2008; He et al., 2009). Alignment of the deduced amino acid sequences of MtPAR and other proteins of the MYB R2R3 family was carried out using ClustalW in the

Geneious software suite (www.Biomatters.com; Biomatters, Auckland, NZ). The phylogenetic tree was built using a Neighbor-Joining algorithm with 100 bootstrap replicates. The R2R3 domain of each MYB factor was identified using the PFAM protein family database (Bateman et al., 2002). GeneBank accession numbers of all amino acid sequences are provided in Table 1.

TABLE 1

GeneBank accession numbers of amino acid sequences used for preparing alignments of FIG. 1c.		
Annotation	Name	Length
Q9ZTC3.1	MYB90 Protein	340
PmMBF1	MYB-like transcriptional factor MBF1 Protein	409
P27900.2	GL1 Protein	316
NP_199744.1	AtMYB111 (myb domain protein 111); DNA binding/transcription factor	388
NP_196979.1	ATMYB66 (MYB DOMAIN PROTEIN 66); DNA binding/protein binding/transcription factor/transcription regulator	316
NP_188966.1	MYB15 (MYB DOMAIN PROTEIN 15); DNA binding/transcription factor	395
NP_182268.1	MYB12 (MYB DOMAIN PROTEIN 12); DNA binding/transcription activator/transcription factor	388
NP_176057.1	PAP1 (PRODUCTION OF ANTHOCYANIN PIGMENT 1); DNA binding/transcription factor protein	340
CAJ90831.1	MYBPA1 protein	388
BAI49719.1	Putative MYB transcription factor Protein	351
BAD18978.1	myb-related transcription factor VvMYBA2 Protein	360
BAD18977.1	Myb-related transcription factor VvMYBA1 Protein	354
BAA21619.1	ATMYB4 Protein	394
ACN79542.1	MYB transcription factor LAP3 Protein	358
ACN79541.1	MYB transcription factor LAP1 Protein	359
ACN79540.1	MYB transcription factor LAP4 Protein	361
ACN79539.1	MYB transcription factor LAP2 Protein	355
ABB83828.1	VENOSA Protein	300
ABB83827.1	ROSEA2 Protein	327
ABB83826.1	ROSEA1 Protein	317
AAV98200.1	MYB-like protein ODORANT1	390
AAS68190.1	Myb transcription factor Protein	404
AAQ55181.1	anthocyanin 1 Protein	363
AAB49039.1	c-myb Protein	643

The gene for one of these MYB TFs, termed MtPAR, encodes a putative MYB TF of the R2R3 class based on the presence of highly-conserved R2 and R3 MYB DNA-binding domains at the N-terminal end of the protein (FIG. 1b) (Stracke et al. 2001). MtPAR was expressed in a seed-specific manner, with maximal expression at 24 days after pollination (DAP; FIG. 1a). We used quantitative reverse-transcription polymerase chain reaction (qRT-PCR) to measure MtPAR transcript levels in dissected seed tissues and found that the gene was expressed in the seed coat but not in the embryo or endosperm (FIG. 1d). Phylogenetic analysis revealed no close relationship between MtPAR and MYB TFs involved in the regulation of anthocyanin (e.g. LAP proteins from *M. truncatula* or ANTHOCYANIN1 from *S. lycopersicum*; Peel et al., 2009; U.S. Patent Appl. Publ. 2005/0203033) or proanthocyanidin biosynthesis (e.g. TRANSPARENT TESTA2 from *A. thaliana* (GenBank Accession AJ299452); or U.S. Pat. No. 7,709,701) or MYBPA1 and MYBPA2 from *V. vinifera*; FIG. 1c; Nesi et al., 2001; Tether et al., 2009). The closest homolog of MtPAR was a MYB protein (Gm-MYB115, GenBank Accession QOPJG9) from *G. max* (soybean) of unknown function.

Par Mutants are Defective in Seed Coat PA Accumulation

Four independent mutants with retrotransposon-insertions in the MtPAR gene were isolated via a PCR-screen of DNA from a Tnt1-insertion mutant population (Tadege et al. 2008). Generation of the *Medicago truncatula* Tnt1 insertional mutant population and growth of R₁ seeds were as described previously (Tadege et al. 2008). Reverse genetic screening for Tnt1 retrotransposon insertions in MtPAR was performed using a nested PCR approach (Cheng et al., 2011). PCR products from target mutant lines were purified with QIAquick™ PCR purification kit (Qiagen) and sequenced using Tnt1 primers to confirm insertions in MtPAR. The primers used were:

F1 : (SEQ ID NO: 5)
TGAGTGGCAGTGGAGTGTCTT;
F2 : (SEQ ID NO: 6)
TAAAGGTGCTTGGTCTCGTGAA,
R1 : (SEQ ID NO: 7)
GGTCTCTAATTTTCCGTCAC,
and
R2 : (SEQ ID NO: 8)
GGTCCCCCATTGGAATAAATC.

Tnt1 insertions were found in the second exon of MtPAR1 in mutant line NF4419 and in the third exon in lines NF2466, NF1358, NF3308 (FIG. 3a). Homozygous insertion mutants of all four lines exhibited the same phenotype, namely a reduction in pigmentation of mature seed compared to the wild-type control (FIG. 2b and FIG. 2a). MtPAR transcript levels in developing seed of the four mutants were less than 5% of the wild-type level, as determined by qRT-PCR (FIG. 2b).

4-Dimethylaminocinnamaldehyde (DMACA) and vanillin staining was performed to evaluate qualitative changes in PA and anthocyanin contents of mature seeds. Seeds were stained overnight and destained in ethanol for observation.

Mature seeds (about 200 mg) of par homozygous mutants and their corresponding null segregant controls, or hairy roots (about 150 mg fresh weight) expressing MtPAR or GUS (as control). For analysis of anthocyanins in mature seeds or hairy roots (16d after subculture), about 200 mg mature seeds or 150 mg fresh hairy roots were ground into powder in liquid nitrogen and extracted three times with 300 µl of methanol containing 0.1% HCl by sonicating for 40 min each time. Pooled extracts were further extracted with an equal volume of chloroform, and the aqueous portion was used for spectrophotometer analysis of anthocyanin at 530 nm absorbance with a spectrophotometer with cyanidin 3-O-glucoside as standard. Epicatechin was used as standard for soluble PA quantification, and the PA dimer procyanidin B1 was used as standard for insoluble PAs. Reverse-phase HPLC for analysis of cyanidin products of butanol-HCl hydrolysis of insoluble PAs and normal phase HPLC coupled to post-column DMACA-derivatization for analysis of composition of soluble PAs in plant samples were conducted as described previously (Zhao and Dixon, 2010). Results of extraction and analysis of flavonoids from seeds and hairy roots of *M. truncatula* were as follows:

catula by UV spectroscopy; DMACA staining; and reverse phase or normal phase HPLC coupled to post-column DMACA-derivatization, UV diode array detection, or mass spectrometry are shown in FIGS. 4-5.

For measurement of flavonoid content, metabolites were extracted from 10.0±0.1 mg of dried mature seeds with 2 ml of 80% methanol containing 18 µg/ml of umbelliferone as internal standard, for 2 h at room temperature. After centrifugation, the supernatants were analyzed using a Waters Acquity HPLC system fitted with a quadrupole time of flight (Q-TOF) Premier mass spectrometer, according to Sumner et al. (2007). Masses of eluted compounds were detected in the negative ESI mode (Sumner et al., 2007). Metabolites were identified based on mass and retention time relative to authentic standards. Relative abundances were calculated using MET-IDEA (Broeckling et al., 2006) and peaks were normalized by dividing each peak area by the value of the internal standard peak area.

The staining indicated a decrease in the proanthocyanidin (PA) content of mature mutant seeds compared to the wild-type (FIG. 2c), whereas vanillin staining revealed no apparent difference in the anthocyanin content between mutant and wild-type seeds (FIG. 2c). DMACA staining of developing seed revealed gradual accumulation of PA from 10 to 16 DAP in both mutant and wild-type. Differences between mutant and wild-type in DMACA-staining of seed first became apparent around 20-24 DAP (FIG. 6a), which coincided with maximal MtPAR expression in the wild-type. DMACA staining was confined largely to seed coats, mirroring the tissue-specificity of MtPAR expression (FIG. 6b).

To confirm that the different seed color between par and sibling wild-type was caused by PA levels, we quantified seed PA content in par mutants and their segregant controls. Both soluble and insoluble PA levels in par seeds were significantly reduced as compared to their segregant controls. Soluble PA content was about 50% lower, and insoluble PA content up to 80% lower in the mutants than in the sibling wild-types (FIG. 3d). We also subjected samples to high performance liquid chromatography (HPLC) followed by post-column DMACA-derivatization to fractionate soluble PAs. Levels of insoluble PAs were detected by measurement of cyanidines revealed after butanol-HCl hydrolysis. Mutant and wild-type seed exhibited a similar spectrum of PAs (FIG. 4). However, the PA content of seeds was much lower in the par mutants. In contrast, spectrophotometer analysis of anthocyanin content was not significantly different between par mutant and wild-type seeds (FIG. 3e). These results indicate that MtPAR regulates proanthocyanidin but not anthocyanin biosynthesis in seeds.

Example 3

Ectopic Expression of MtPAR Induces Pa Biosynthesis

MtPAR Regulates Expression of Pa Biosynthesis Genes

To demonstrate a role for MtPAR in PA biosynthesis, *M. truncatula* roots were transformed with the MtPAR cDNA coupled to the constitutively-active CaMV-35S promoter (Odell et al., 1985).

The open reading frame (ORF) of MtPAR was amplified from cDNA synthesized from developing pods of ecotype R108 using the Trizol® RNA extraction method (Invitrogen) and Superscript III reverse transcriptase (Invitrogen). The primer sequences used for amplification were forward

primer: ATGGTTAGAAGTCCTAAGGAGGTT (SEQ ID NO:9); and reverse primer: TCAATCATTTCACAGTCAAGAAAG (SEQ ID NO:10). PCR products were cloned into the entry vector pENTR/D/TOPO (Invitrogen). After sequencing to validate the sequence of MtPAR in the entry vector, the ORF was recombined into a destination vector, pB7WG2D using the LR clonase reaction (Invitrogen). The GUS gene was also recombined into pB7WG2D vector, which was then used as a control for the hairy root transformation.

pB7WG2D vectors harboring MtPAR or GUS sequences were transformed into *Agrobacterium rhizogenes* strain ARqua 1 by electroporation (Quandt et al., 1993). Transformed colonies were grown on LB-agar medium at 28° C., with spectinomycin and streptomycin for vector selection. After confirmation by PCR, transformed *Agrobacterium* were used to transform leaves of *M. truncatula* (cv. Jemalong A17). The resulting hairy roots were maintained on B5 agar media in Petri dishes supplied with 7.5 mg/l phosphinothricin under fluorescent light (140 µE/m²·s⁻¹) with a 16-h photoperiod, and were sub-cultured every 20 days onto fresh media. Screening of hairy root clones was done by observation under UV light for GFP signal, by staining with DMACA reagent for presence of PAs, and by qRT-PCR analysis to detect and quantify the MtPAR transcript level.

Agrobacterium rhizogenes (strain ARqua 1, Quandt et al., 1993) was used to transfer the p35S::MtPAR construct into *M. truncatula* together with a Green Fluorescent Protein (GFP) gene that enabled identification of transformed hairy roots (FIG. 7a). Ectopic expression of MtPAR in *Medicago* hairy roots was checked by qRT-PCR (FIG. 8). Initial observations of unstained hairy roots revealed an increase in red pigmentation in transgenic roots containing the p35S::MtPAR construct compared to control transformed roots containing a p35S::GUS (β-glucuronidase; Jefferson et al., 1987) construct (FIG. 7a). No differences in root growth or other morphological features were observed between p35S::MtPAR-containing and control plants. Subsequent staining of hairy roots with DMACA revealed a dramatic difference between p35S::MtPAR- and p35S::GUS-transformed roots. The former stained dark green with DMACA, whereas the latter (control) did not (FIG. 3a).

Quantitative analysis of PA content confirmed that ectopic expression of MtPAR induced PA biosynthesis in hairy roots. Soluble PA levels were low in hairy roots of control transformed plants (p35S::GUS) but were up to 100-fold higher in some p35S::MtPAR lines (FIG. 7b). A positive correlation was observed between soluble PA content and MtPAR transcript levels in the different transgenic lines (FIG. 7b). However, no significant difference in levels of insoluble PA was found between control and p35S::MtPAR lines (FIG. 8). Anthocyanin content was relatively high in hairy roots of control plants but decreased with increasing soluble PA levels in p35S::MtPAR lines.

To determine the mechanism by which MtPAR triggers PA biosynthesis, transcriptome analysis of mutant and wild-type seeds and of p35S::MtPAR- and p35S::GUS-transformed roots was performed, using Affymetrix *Medicago* GENE-CHIPS. Total RNA was isolated from developing seeds using a modified CTAB method (Verdier et al., 2008) and from hairy roots using Trizol reagent, according to the manufacturer's instructions (Invitrogen). Ten µg of total RNA from each sample were DNase treated (Turbo DNase, Ambion, Austin, Tex.) and partially purified (RNeasy MinElute Cleanup kit, Qiagen), according to manufacturer's instructions. Five hundred ng of purified RNA for each of the three biological replicates was used for probe synthesis using a

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GeneChip 3' IVT express kit, according to manufacturer's instructions (Affymetrix, Santa Clara, Calif.). Hybridization of probes to Affymetrix GeneChip® *Medicago* genome arrays and scanning of arrays was carried out as described previously (Benedito et al., 2008). Raw data were normalized by robust multichip averaging (RMA), as described in Irizarry et al. (2003). Presence and absence calls for probesets were obtained using the dCHIP algorithm (Li and Wong, 2001). Differentially-expressed genes in mutant and over-expressing lines were identified using the associative analysis described in Dozmorov and Centola (2003). Type I family-wise error rate was reduced by using a Bonferroni corrected p-value (threshold 0.05). False discovery rate was controlled by calculating the q-value using extraction of differential gene expression (EDGE, Biostat, Leek et al., 2005). To identify differentially regulated probesets, we used a p-value threshold of 5% and at least a 2-fold difference between transformant/mutant lines and their respective controls.

qRT-PCR analysis was performed using cDNA synthesized by SuperScript III from 2 µg of DNase treated RNA, according to manufacturer's instructions (Invitrogen). Amplification reactions were performed in 5 µl final volume containing 2.5 µl of Power SYBR mastermix (Applied Biosystems), 1 µl of primers (0.5 µM of each primers) and 1.5 µl of 1:30 diluted cDNA. qRT-PCR data were generated using an Applied Biosystems 7900HT instrument and analyzed using SDS software (Applied Biosystems). PCR efficiencies were calculated using the LinReg software (Ramakers et al., 2003). Transcript levels were normalized using the geometric average of two housekeeping genes, MSC27 (TC85211) and PDF2 (TC107161) (Verdier et al., 2008). Primer sequences used were: primer pair for MSC27: GTTGAAGTAGACAT-TGGTGCTAACG (SEQ ID NO:11) and AGCTGAGTCAT-CAACACCCTCAT (SEQ ID NO:12); and primer pair for PDF2: GTGTTTTGCTTCCGCCGTT (SEQ ID NO:13), and CCAAATCTTGCTCCCTCATCTG (SEQ ID NO:14). Additional primers for qRT-PCR were:

WD40 qPCR Forward primer: (SEQ ID NO: 15)
ACCAACTACACCGGTCGCGG,
WD40 qPCR Reverse primer: (SEQ ID NO: 16)
GCTACAGCCGGCAACTCCCA;

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-continued

MtTT2like qPCR Forward primer: (SEQ ID NO: 17)
CGTCCATCCGTCAAACGCGG,
MtTT2like qPCR Reverse primer: (SEQ ID NO: 18)
ACGGTGGAGGCGGAGGATGA;
MtANRqPCR Forward primer: (SEQ ID NO: 19)
GCAAAGCCACCCACTTGGGGTT,
MtANRqPCR Reverse primer: (SEQ ID NO: 20)
TCAGCAAATTTCCACGCAGCCT;
MtTT2like qPCR Forward primer #2: (SEQ ID NO: 21)
ACGACGATGCATTGCTGCACAC;
MtTT2like qPCR Reverse primer #2: (SEQ ID NO: 22)
GGCGGCGATTCCACAGAGC;
MtPARqPCR Forward primer: (SEQ ID NO: 23)
AGCCAACATCATCATCATCATTGCCA,
MtPARqPCR Reverse primer: (SEQ ID NO: 24)
AGGCTTTGGAGCTTCTGGTGCT.

Comparisons of transcript levels in seed at 20 DAP identified 49 genes that were differentially-expressed (transcript ratio <0.5 or >2; p-value <0.05) between par mutants (lines NF2466, NF3308 and NF4419) and their wild-type siblings. Of these, 38 genes exhibited lower- and 11 genes exhibited higher transcript levels in the mutants (Table 2). According to GeneBins ontology (Goffard and Weiller, 2007), 14 of the genes that were 'repressed' in the mutants encode enzymes involved in flavonoid biosynthesis. Some of these genes/enzymes are required for both PA and anthocyanin synthesis (e.g. chalcone synthase, CHS; flavonoid 3'-hydroxylase, F3H; and leucoanthocyanidin dioxygenase (LDOX; also termed ANS)), while others act downstream in metabolism and are specific to PA biosynthesis (e.g. anthocyanidin reductase ANR, glucosyltransferase UGT72L1). Genes that were more highly expressed in the mutants were mostly of unknown function (Table 2).

TABLE 2

List of probesets down- and up-regulated in par mutants by more than two-fold and also at a statistically significant level (p-value <5%). Probesets are found at *Medicago truncatula* Gene Expression Atlas ("MtGEA"; Benedito et al., 2008; He et al., 2009).

Probesets	Target Description	Ave WT	SD WT	Ave par
Mtr.20567.1.S1_at	IMGAG 1115.m00010 /FEA = mRNA /DEF = Type III polyketide synthase; Naringenin-chalcone synthase AC146683.9.91 50180 48876 mth2-179n10 Jan. 13, 2005	859.643182	428.177702	5.878338
Mtr.36333.1.S1_at	BE248436 /FEA = mRNA /DEF = similar to UPIQ84JJ4 (Q84JJ4) Flavonoid 3'-hydroxylase (Fragment), partial (21%)	1671.23062	589.880834	45.80479
Mtr.6517.1.S1_at	BQ147749 /FEA = mRNA /DEF = similar to UPIQ84J65 (Q84J65) Gray pubescence flavonoid 3'-hydroxylase, partial (49%)	233.108836	71.1217427	11.46001
Mtr.49572.1.S1_s_at	IMGAG 1104.m00016 /FEA = mRNA /DEF = Naringenin-chalcone synthase; Type III polyketide synthase AC146575.3.161 92557 91179 mth2-145m4 Jan. 13, 2005	598.355904	174.894912	29.87211

TABLE 2-continued

List of probesets down- and up-regulated in par mutants by more than two-fold and also at a statistically significant level (p-value <5%). Probesets are found at <i>Medicago truncatula</i> Gene Expression Atlas ("MtGEA;" Benedito et al., 2008; He et al., 2009).				
Mtr.20187.1.S1__x__at	IMGAG 1104.m00017 /FEA = mRNA /DEF = Naringenin-chalcone synthase; Type III polyketide synthase AC146575.3.171 96668 95373 mth2-145m4 Jan. 13, 2005	1463.82328	192.448074	80.56568
Mtr.20187.1.S1__at	IMGAG 1104.m00017 /FEA = mRNA /DEF = Naringenin-chalcone synthase; Type III polyketide synthase AC146575.3.171 96668 95373 mth2-145m4 Jan. 13, 2005	3779.97877	423.949372	220.1103
Mtr.14017.1.S1__at	TC99980 /FEA = mRNA /DEF = weakly similar to UP LDOX__ARATH (Q96323) Leucoanthocyanidin dioxygenase (LDOX) (Leucoanthocyanidin oxygenase) (Leucoanthocyanidin hydroxylase) (Anthocyanidin synthase) (ANS), partial (19%)	320.922409	158.721654	20.08867
Mtr.39897.1.S1__at	TC105988 /FEA = mRNA /DEF = similar to UP P93697 (P93697) CPRD12 protein, partial (61%)	1916.82201	764.031111	152.5205
Mtr.49572.1.S1__x__at	IMGAG 1104.m00016 /FEA = mRNA /DEF = Naringenin-chalcone synthase; Type III polyketide synthase AC146575.3.161 92557 91179 mth2-145m4 Jan. 13, 2005	97.5854467	18.8400876	12.78775
Mtr.21996.1.S1__x__at	1578.m00031 /FEA = mRNA /DEF = AC124966.27 4823 6271 mth2-8i15 weakly similar to UP Q8S996 (Q8S996) Glucosyltransferase-13 (Fragment)	492.816558	117.195381	73.31215
Mtr.44985.1.S1__at	TC98546 /FEA = mRNA /DEF = UP Q84XT1 (Q84XT1) Anthocyanidin reductase, complete	659.987412	268.830912	109.3382
Mtr.50541.1.S1__at	IMGAG 1054.m00009 /FEA = mRNA /DEF = Myb, DNA-binding; Homeodomain-like AC144645.17.81 55517 54273 mth2-11e15 Jan. 13, 2005	124.145527	46.9606818	24.41019
Mtr.28714.1.S1__at	BI311259 /FEA = mRNA /DEF = homologue to PRF 1609233A 226868 1609233A chalcone synthase 3. { <i>Sinapis alba</i> }, partial (12%)	47.8662293	19.0123022	10.27827
Mtr.16432.1.S1__at	IMGAG 824.m00011 /FEA = mRNA /DEF = Myb, DNA-binding; Homeodomain-like AC129092.13.101 59248 60901 mth2-17n16 Jan. 13, 2005	194.699929	80.1064012	44.75606
Mtr.44170.1.S1__at	TC96829 /FEA = mRNA /DEF =	51.9129817	20.5943212	12.56979
Mtr.41031.1.S1__at	TC108579 /FEA = mRNA /DEF = homologue to PIR PQ0772 PQ0772 4-coumarate-CoA ligase (clone GM4CL1B) - soybean (fragment) { <i>Glycine max</i> }, partial (62%)	652.108309	255.535998	158.1682
Mtr.42595.1.S1__at	TC111920 /FEA = mRNA /DEF = similar to UP Q94EH4 (Q94EH4) At1g48100/F21D18__17, partial (52%)	85.8797083	16.2812939	22.91909
Mtr.9864.1.S1__at	TC104661 /FEA = mRNA /DEF = similar to PIR T51355 T51355 membrane protein [imported] - <i>Arabidopsis thaliana</i> (fragment) { <i>Arabidopsis thaliana</i> }, partial (37%)	43.612151	10.5148258	13.76203
Mtr.13370.1.S1__at	TC97820 /FEA = mRNA /DEF = similar to UP O24623 (O24623) Gibberellin 3 beta-hydroxylase, partial (55%)	79.8549723	23.4285299	27.89866
Mtr.10917.1.S1__at	TC108343 /FEA = mRNA /DEF = similar to UP C773__SOYBN (O48928) Cytochrome P450 77A3, partial (95%)	199.850989	49.111823	73.35225
Mtr.2632.1.S1__at	BI311277 /FEA = mRNA /DEF = homologue to UP Q8LJQ5 (Q8LJQ5) LEC1-like protein, partial (58%)	1280.85869	362.827026	506.9417
Mtr.38379.1.S1__at	TC102674 /FEA = mRNA /DEF = weakly similar to UP Q6GQH4 (Q6GQH4) Egr1 protein, partial (8%)	43.109902	10.9364836	17.33879

TABLE 2-continued

List of probesets down- and up-regulated in par mutants by more than two-fold and also at a statistically significant level (p-value <5%). Probesets are found at <i>Medicago truncatula</i> Gene Expression Atlas ("MtGEA;" Benedito et al., 2008; He et al., 2009).				
Mtr.50478.1.S1__at	IMGAG1968.m00002 /FEA = mRNA /DEF = Phenylalanine/histidine ammonia-lyase; L-Aspartase-like; Phenylalanine ammonia-lyase AC140028.21.21 6624 2477 mth2- 7e24 Jan. 13, 2005	200.937703	46.7852944	81.43143
Mtr.5901.1.S1__at	BG451575 /FEA = mRNA /DEF = similar to UP ST14__SOLTU (Q41495) STS14 protein precursor, partial (49%)	536.655108	87.7948319	218.503
Mtr.26465.1.S1__s__at	1520.m00027 /FEA = mRNA /DEF = AC138199.22 70888 78437 mth2-15g10 similar to UP PEAM__SPIOL (Q9M571) Phosphoethanolamine N- methyltransferase (EC 2.1.1.103)	10.399725	0.89274666	4.373235
Mtr.38932.1.S1__at	TC103858 /FEA = mRNA /DEF = similar to UP MASY__SOYBN (P45458) Malate synthase, glyoxysomal (MS) (Fragment), partial (39%)	215.131423	16.8692609	94.76488
Mtr.10989.1.S1__at	TC108525 /FEA = mRNA /DEF=	20.541302	3.52727699	9.278425
Mtr.48911.1.S1__at	IMGAG1754.m00021 /FEA = mRNA /DEF = Short-chain dehydrogenase/ reductase SDR; Glucose/ribitol dehydrogenase AC123572.15.211 87481 89526 mth2-2b2 Jan. 13, 2005	49.8156177	6.93616061	22.8149
Mtr.27388.1.S1__s__at	AW775333 /FEA = mRNA /DEF = UP Q8GTY4 (Q8GTY4) Rubisco activase (Fragment), partial (81%)	120.199138	12.1398853	55.87101
Mtr.35526.1.S1__at	TC105231 /FEA = mRNA /DEF=	147.897155	46.015984	69.77271
Mtr.37221.1.S1__at	TC100154 /FEA = mRNA /DEF = homologue to UP Q43437 (Q43437) Photosystem II type I chlorophyll a/b-binding protein precursor, complete	489.390869	115.52534	233.2353
Mtr.10393.1.S1__at	TC106621 /FEA = mRNA /DEF = similar to UP Q9SLR8 (Q9SLR8) Thiamin biosynthetic enzyme, partial (91%)	1563.74757	459.862458	753.3561
Mtr.37657.1.S1__at	TC101144 /FEA = mRNA /DEF = similar to UP Q96400 (Q96400) Nitrite transporter, partial (88%)	143.541663	29.9639896	70.27863
Msa.1297.1.S1__at	iMsa.1297 /TID = Msa.1297.1 /CNT = 1 /FEA = mRNA /TIER = ConsEnd /STK = 0 /NOTE = sequence(s) not in UniGene /DEF=	1109.9202	59.2233123	543.7646
Mtr.9046.1.S1__at	TC102211 /FEA = mRNA /DEF = similar to UP GST1__LYCES (P27057) GAST1 protein precursor, partial (60%)	732.975163	157.254025	360.5397
Mtr.12246.1.S1__at	TC94105 /FEA = mRNA /DEF = UP O24099 (O24099) MtN12 protein (Fragment), complete	30.3397733	5.37213744	14.93328
Mtr.12374.1.S1__at	TC94561 /FEA = mRNA /DEF = homologue to PIR S20941 S20941 protochlorophyllide reductase precursor - garden pea { <i>Pisum sativum</i> ;}, complete	4453.53702	711.490929	2208.304
Mtr.37215.1.S1__at	TC100145 /FEA = mRNA /DEF = homologue to UP Q43437 (Q43437) Photosystem II type I chlorophyll a/b-binding protein precursor, complete	85.5805213	20.0459827	42.55927
Mtr.25647.1.S1__at	1444.m00049 /FEA = mRNA /DEF = AC146630.25 121131 117741 mth2-7f22 weakly similar to UP O64548 (O64548) YUP8H12R.38 protein	68.1816447	16.1134736	137.2836
Mtr.40882.1.S1__at	TC108249 /FEA = mRNA /DEF = weakly similar to UP Q8W033 (Q8W033) Aldehyde dehydrogenase, partial (84%)	86.9470197	7.1879305	176.0712
Mtr.44363.1.S1__at	TC97216 /FEA = mRNA /DEF = similar to UP Q93ZQ5 (Q93ZQ5) AT4g22990/F7H19_170, partial (29%)	51.907178	12.684616	108.9426

TABLE 2-continued

List of probesets down- and up-regulated in par mutants by more than two-fold and also at a statistically significant level (p-value <5%). Probesets are found at <i>Medicago truncatula</i> Gene Expression Atlas ("MtGEA;" Benedito et al., 2008; He et al., 2009).					
Mtr.43455.1.S1__at	TC95369 /FEA = mRNA /DEF = weakly similar to GB AAL15368.1 16323268 AY057738 At1g15670/F7H2_1 { <i>Arabidopsis thaliana</i> };, partial (49%)	59.199118	18.553866	135.8152	
Mtr.40913.1.S1__at	TC108317 /FEA = mRNA /DEF = similar to UP Q6CXP0 (Q6CXP0) <i>Kluyveromyces lactis</i> strain NRRL Y-1140 chromosome A of strain NRRL Y-1140 of <i>Kluyveromyces lactis</i> , partial (4%)	54.0917987	14.8964758	129.4808	
Mtr.48521.1.S1__at	IMGAG 1169.m00022 /FEA = mRNA /DEF = putative low-molecular-weight cysteine-rich protein lcr19 precursor, putative AC147407.10.221 75050 75673 mth2-159b14 Jan. 13, 2005	42.7850667	4.79186431	104.0712	
Mtr.38412.1.S1__at	TC102743 /FEA = mRNA /DEF = UP Q5WET6 (Q5WET6) Phosphate ABC transporter permease, partial (5%)	62.7663617	8.53194602	171.3022	
Mtr.43887.1.S1__at	TC96246 /FEA = mRNA /DEF = similar to GB AAP88343.1 32815917 BT009709 At3g13310 { <i>Arabidopsis thaliana</i> };, partial (31%)	419.161484	112.701881	1167.374	
Mtr.39929.1.S1__at	TC106102 /FEA = mRNA /DEF = homologue to UP O24082 (O24082) 17 kD heat shock protein, partial (76%)	43.2521373	7.45366017	144.1983	
Mtr.21943.1.S1__s__at	1575.m00026 /FEA = mRNA /DEF = AC124216.19 211 2394 mth2-34o22 weakly similar to UP O48924 (O48924) CYP83D1p (Fragment)	24.0987247	3.23843614	88.50047	
Mtr.21943.1.S1__x__at	1575.m00026 /FEA = mRNA /DEF = AC124216.19 211 2394 mth2-34o22 weakly similar to UP O48924 (O48924) CYP83D1p (Fragment)	54.040693	27.3305952	207.9964	
	Probesets	SD par	Pts	Pta	Ratio(par/WT)
	Mtr.20567.1.S1__at	0.921726	0.025969	0	0.006838114
	Mtr.36333.1.S1__at	38.48854	0.008888	0	0.027407824
	Mtr.6517.1.S1__at	3.963385	0.005732	0	0.049161643
	Mtr.49572.1.S1__s__at	8.198254	0.004916	0	0.04992365
	Mtr.20187.1.S1__x__at	38.15873	0.000258	0	0.0505037848
	Mtr.20187.1.S1__at	100.2211	0.000145	0	0.058230557
	Mtr.14017.1.S1__at	2.819671	0.030434	0	0.062596644
	Mtr.39897.1.S1__at	94.02205	0.016543	1.015E-231	0.079569453
	Mtr.49572.1.S1__x__at	3.465614	0.001556	0	0.131041565
	Mtr.21996.1.S1__x__at	7.812866	0.00347	0	0.148761539
	Mtr.44985.1.S1__at	86.77618	0.027882	4.2247E-28	0.165667143
	Mtr.50541.1.S1__at	21.49587	0.028708	9.2613E-16	0.196625637
	Mtr.28714.1.S1__at	3.599841	0.028186	4.163E-73	0.214729135
	Mtr.16432.1.S1__at	9.913184	0.032357	2.766E-151	0.229871984
	Mtr.44170.1.S1__at	4.820915	0.032225	2.3066E-45	0.242131973
	Mtr.41031.1.S1__at	53.71319	0.030605	4.0683E-57	0.242548922
	Mtr.42595.1.S1__at	10.58873	0.004944	7.1366E-25	0.266874288
	Mtr.9864.1.S1__at	2.61025	0.008826	2.5807E-87	0.315554878
	Mtr.13370.1.S1__at	17.10545	0.036143	1.4331E-07	0.349366589
	Mtr.10917.1.S1__at	9.86689	0.011932	3.019E-109	0.367034687
	Mtr.2632.1.S1__at	153.77	0.027237	2.8485E-18	0.395782719
	Mtr.38379.1.S1__at	2.320878	0.01623	1.9724E-82	0.402199662
	Mtr.50478.1.S1__at	37.24986	0.025789	2.7473E-08	0.405257109
	Mtr.5901.1.S1__at	35.32962	0.004332	7.5638E-55	0.407157245
	Mtr.26465.1.S1__s__at	0.212616	0.000341	0	0.420514517
	Mtr.38932.1.S1__at	34.44285	0.005558	0	0.44049762
	Mtr.10989.1.S1__at	2.38271	0.010161	2.6732E-16	0.451696067
	Mtr.48911.1.S1__at	6.415001	0.007761	3.0952E-13	0.457986934
	Mtr.27388.1.S1__s__at	18.17099	0.00699	0	0.464820358
	Mtr.35526.1.S1__at	13.27917	0.04757	2.1964E-24	0.471765032
	Mtr.37221.1.S1__at	88.71524	0.038178	5.7002E-07	0.476582784
	Mtr.10393.1.S1__at	204.4556	0.049359	6.6375E-12	0.481763243
	Mtr.37657.1.S1__at	16.2329	0.02041	5.4025E-15	0.489604419
	Msa.1297.1.S1__at	92.8636	0.00088	0	0.489913204
	Mtr.9046.1.S1__at	117.02	0.030189	3.5369E-08	0.491885269
	Mtr.12246.1.S1__at	4.840689	0.021016	3.5356E-08	0.492201425
	Mtr.12374.1.S1__at	448.7319	0.009858	4.4629E-18	0.495854053
	Mtr.37215.1.S1__at	11.79179	0.032776	2.6288E-10	0.497300873

TABLE 2-continued

List of probesets down- and up-regulated in par mutants by more than two-fold and also at a statistically significant level (p-value <5%). Probesets are found at <i>Medicago truncatula</i> Gene Expression Atlas ("MtGEA;" Benedito et al., 2008; He et al., 2009).					
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Mtr.25647.1.S1__at	18.84132	0.008475	1.104E-13	2.013497826	
Mtr.40882.1.S1__at	36.82668	0.014683	2.615E-102	2.025039509	
Mtr.44363.1.S1__at	7.173214	0.002471	0	2.098795732	
Mtr.43455.1.S1__at	0	0.002022	0	2.294209468	
Mtr.40913.1.S1__at	33.92323	0.024354	1.8567E-18	2.393723809	
Mtr.48521.1.S1__at	19.671	0.006327	9.921E-109	2.43241952	
Mtr.38412.1.S1__at	63.87284	0.043361	1.372E-107	2.729203697	
Mtr.43887.1.S1__at	201.8901	0.004976	1.3369E-30	2.7850214	
Mtr.39929.1.S1__at	60.96489	0.046549	1.11E-121	3.333900686	
Mtr.21943.1.S1__s__at	27.47733	0.015711	5.414E-260	3.672413176	
Mtr.21943.1.S1__x__at	27.87122	0.002402	0	3.848884118	

Genes corresponding to 171 probe-sets were significantly altered (transcript ratio <0.5 or >2; p-value <0.05) in expression in *M. truncatula* hairy roots transformed with p35S::MtPAR compared to p35S:: GUS-transformed controls

(Table 3). One hundred and fifteen of these exhibited higher transcript levels in p35S::MtPAR roots. Eleven of the 115 genes code for putative enzymes of flavonoid biosynthesis (e.g. CHS, F3H, and ANS).

TABLE 3

List of probesets down- and up-regulated in transformed hairy roots by more than two-fold and also at a statistically significant level (p-value <5%). Probesets are found at <i>Medicago truncatula</i> Gene Expression Atlas ("MtGEA;" Benedito et al., 2008; He et al., 2009).												
Probesets	Transcript ID(Array Design)	Target Description	Representative Public ID	Ave OE-GUS	SD OE-GUS	Ave OE-PAR	SD OE-PAR	PTS	PTA	Ratio (OE-PAR:OE-GUS)		
Mtr:50541.1.S1_at	Mtr:50541.1	IMGAG1054.m00009 /FEA = mRNA /DEF = Myb, DNA-binding; Homeodomain-like AC144645.17.81 55517 54273 mth2-11e15 Jan. 13, 2005	IMGAG1054.m00009	9.982159	2.410535	1045.049	170.3748	0.000461	0	104.6917		
Mtr:31745.1.S1_at	Mtr:31745.1	AL378024 /FEA = mRNA /DEF = UP/Q635K2 (Q635K2) Possible acetoin transport permease, partial (2%)	AL378024	5.652491	1.040688	496.1846	87.22061	0.000622	0	87.78158		
Mtr:15215.1.S1_at	Mtr:15215.1	IMGAG732.m00014 /FEA = mRNA /DEF = unnamed protein product; contains similarity to unknown protein gb AAB70446.1 gene_id: K24M7.6 AC121244.13.131 60816 57747 mth2-31b9 Jan. 13, 2005	IMGAG732.m00014	9.69528	1.563699	810.6132	185.9664	0.001726	0	83.60905		
Mtr:9657.1.S1_at	Mtr:9657.1	TC103993 /FEA = mRNA /DEF = similar to UP/O04197 (O04197) Coronatine-insensitive 1 (COI1), AtFBL2 (Atg39940/T28M21.10) (LRR-containing F-box protein), partial (53%)	TC103993	7.059164	0.754961	170.0771	13.77901	3.37E-05	0	24.09309		
Mtr:3831.1.S1_at	Mtr:3831.1	BI265054 /FEA = mRNA /DEF = TC104048 /FEA = mRNA /DEF = similar to GB AAS09999.1/41618996/AY519529 MYB transcription factor (<i>Arabidopsis thaliana</i>); partial (43%)	BI265054 TC104048	21.38637 14.71274	6.771167 1.652201	238.3361 152.5719	100.6331 19.95448	0.020375 0.000283	0 0	11.1443 10.37005		
Mtr:42658.1.S1_at	Mtr:42658.1	TC112097 /FEA = mRNA /DEF = similar to UP/Q8K0R3 (Q8K0R3) Ski protein (Fragment), partial (6%)	TC112097	18.72994	4.976025	153.4187	36.96635	0.003333	0	8.191094		
Mtr:47022.1.S1_s_at	Mtr:47022.1	1705.m00036 /FEA = mRNA /DEF = AC148359.19 17939 18394 mth2-22k11 weakly similar to TAIR gene: 2181071-GOsep. 168412. m00083 expressed protein wound-inducible protein wun1 protein - <i>Solanum</i>	1705.m00036	29.80183	3.491729	175.7989	71.83741	0.02454	0	5.898927		
Mtr:17550.1.S1_at	Mtr:17550.1	IMGAG1003.m00011 /FEA = mRNA /DEF = Plant lipid transfer protein/Par allergen; Plant lipid transfer/seed storage/trypsin-alpha amylase inhibitor AC141322.24.111 47012 45856 mth2-8e1 Jan. 13, 2005	IMGAG1003.m00011	61.13021	21.97928	350.3567	162.9343	0.038141	5.5E-115	5.731319		
Mtr:2667.1.S1_at	Mtr:2667.1	BM779752 /FEA = mRNA /DEF = BG448288 /FEA = mRNA /DEF =	BM779752 BG448288	17.98985 32.79162	5.494132 8.562886	98.90028 177.3127	18.50033 39.25415	0.00191 0.00338	1.6E-143 7.4E-188	5.497561 5.407256		

TABLE 3-continued

List of probesets down- and up-regulated in transformed hairy roots by more than two-fold and also at a statistically significant level (p-value <5%). Probesets are found at <i>Medicago truncatula</i> Gene Expression Atlas ("MtGEA," Benedetto et al., 2008; He et al., 2009).										
Probesets	Transcript ID(Array Design)	Target Description	Representative Public ID	Ave OE-GUS	SD OE-GUS	Ave OE-PAR	SD OE-PAR	PTS	PTA	Ratio (OE-PAR:OE-GUS)
Mtr.40380.1.S1_at	Mtr.40380.1	TC107167 /FEA = mRNA /DEF = weakly similar to UP/Q9SB32 (Q9SB32) SRG1-like protein (At4g25310), partial (44%)	TC107167	55.38911	51.94652	293.7718	47.75451	0.004255	0	5.303782
Mtr.1872.1.S1_at	Mtr.1872.1	BF239373 /FEA = mRNA /DEF = weakly similar to GB/CAA66109.3/48426429/CANST2PRO specific tissue protein 2 {Cicer arietinum}, partial (27%)	BE239373	85.49441	51.09398	449.4508	141.4529	0.01379	5.66E-35	5.257078
Mtr.31025.1.S1_at	Mtr.31025.1	TC96845 /FEA = mRNA /DEF =	TC96845	102.841	112.6199	507.1613	20.85026	0.003622	0	4.931511
Mtr.20567.1.S1_at	Mtr.20567.1	IMGAG1115.m00010 /FEA = mRNA /DEF = Type III polyketide synthase; Narigenin-chalcone synthase	IMGAG1115.m00010	247.7764	32.64647	1164.871	418.3995	0.019352	0	4.701298
Mtr.42945.1.S1_x_at	Mtr.42945.1	AC146683.9.91.50180.48876.mth2-179p10 Jan. 13, 2005	TC94166	21.43954	12.09383	98.20516	9.756303	0.001024	0	4.580564
Msa.3084.1.S1_at	Msa.3084.1	iMsa.3084 /TID = Msa.3084.1 /CNT = 1 /FEA = mRNA /TIER = ConsEnd /STK = 0 /NOTE = sequence(s) not in UniGene	TC87	24.4536	3.089405	103.2631	35.34588	0.018346	0	4.222819
Mtr.43960.1.S1_at	Mtr.43960.1	TC96409 /FEA = mRNA /DEF = weakly similar to UP/Q6TDU2 (Q6TDU2) Coronatine-insensitive 1, partial (31%)	TC96409	8.572815	1.205952	35.28415	8.621999	0.006029	0	4.115818
Mtr.33715.1.S1_at	Mtr.33715.1	BF265542 /FEA = mRNA /DEF =	BF265542	10.36655	1.75463	41.11893	18.60234	0.046364	2.1E-202	3.966501
Mtr.25016.1.S1_at	Mtr.25016.1	1785.m00050 /FEA = mRNA /DEF = AC155890.1 50797 51458 mth2-49p3	1785.m00050	35.53711	3.06294	140.4745	15.86264	0.000356	0	3.952895
Mtr.14017.1.S1_at	Mtr.14017.1	TC99980 /FEA = mRNA /DEF = weakly similar to UP/LDOX_ARATH (Q96323) Leucoanthocyanidin dioxygenase (LDOX) (Leucoanthocyanidin hydroxylase) (Leucoanthocyanidin synthase) (Anthocyanidin synthase) (ANS), partial (19%)	TC99980	17.83044	0.618886	68.77901	9.081704	0.000634	0	3.857393
Mtr.38212.1.S1_at	Mtr.38212.1	TC102299 /FEA = mRNA /DEF = similar to UP/SOCL_ARATH (O64645) SUPPRESSOR OF CONSTANS OVEREXPRESSION 1 protein (Agamous-like MADS box protein AGL20), partial (84%)	TC102299	196.2747	110.7566	738.9281	77.19826	0.002237	0	3.764765
Mtr.46868.1.S1_s_at	Mtr.46868.1	1721.m00028 /FEA = mRNA /DEF = AC149580.15 36711 40336 mth2-123f14 similar to UP/Q43817 (Q43817) Lipoxigenase (EC 1.13.11.12)	1721.m00028	38.47225	31.34234	138.5788	39.3427	0.026125	3.16E-08	3.602047

TABLE 3-continued

List of probesets down- and up-regulated in transformed hairy roots by more than two-fold and also at a statistically significant level (p-value <5%). Probesets are found at <i>Medicago truncatula</i> Gene Expression Atlas ("MGEA," Benedetto et al., 2008; He et al., 2009).										
Probesets	Transcript ID(Array Design)	Target Description	Representative Public ID	Ave OE-GUS	SD OE-GUS	Ave OE-PAR	SD OE-PAR	PTS	PTA	Ratio (OE-PAR:OE-GUS)
Mtr.10725.1.S1_at	Mtr.10725.1	TC107714 /FEA = mRNA /DEF = similar to UP/Q9ZRV5 (Q9ZRV5) Basic blue copper protein, partial (98%)	TC107714	848.5854	50.51791	2933.289	161.1705	2.83E-05	0	3.456681
Mtr.46870.1.S1_at	Mtr.46870.1	1721.m00025 /FEA = mRNA /DEF = AC149580.15 18018 21534 mth2-123f14 similar to UPILOX1_I LENCU (P38414) Lipoxigenase (EC 1.13.11.12)	1721.m00025	24.82831	18.46775	84.59721	18.02103	0.01597	9.22E-09	3.407288
Mtr.23228.1.S1_at	Mtr.23228.1	1661.m00045 /FEA = mRNA /DEF = AC145109.33 24251 23742 mth2-25f20	1661.m00045	481.0663	167.7122	1608.402	289.3998	0.004292	2.5E-31	3.343411
Mtr.10812.1.S1_at	Mtr.10812.1	TC107993 /FEA = mRNA /DEF = similar to UP/C7DA_SOYBN (O48923) Cytochrome P450 71D10, partial (71%)	TC107993	35.46236	27.08208	116.591	17.66899	0.0122	1.78E-15	3.287739
Mtr.29429.1.S1_at	Mtr.29429.1	CX532222 /FEA = mRNA /DEF = AJ504073 /FEA = mRNA /DEF = similar to UP/Q801G7 (Q801G7) Ribosomal protein S3 (Fragment), partial (33%)	CX532222	22.21847	2.858976	72.88519	6.525392	0.00025	0	3.280387
Mtr.31339.1.S1_at	Mtr.31339.1	TC94971 /FEA = mRNA /DEF = similar to UP/Q84KK6 (Q84KK6) S-adenosyl-L-methionine: 2,7,4'-trihydroxyisoflavanone 4'-O-methyltransferase, partial (97%)	AJ504073	8.439299	1.466162	26.49642	3.058862	0.000769	0	3.139647
Mtr.43282.1.S1_at	Mtr.43282.1	TC94971 /FEA = mRNA /DEF = similar to UP/Q84KK6 (Q84KK6) S-adenosyl-L-methionine: 2,7,4'-trihydroxyisoflavanone 4'-O-methyltransferase, partial (97%)	TC94971	142.4577	48.42814	445.1406	64.56671	0.002897	2.6E-27	3.124721
Mtr.37050.1.S1_at	Mtr.37050.1	TC111252 /FEA = mRNA /DEF = UP/Q8J8G6 (Q8J8G6) Envelope glycoprotein (Fragment), partial (6%)	TC111252	42.01327	22.34994	129.683	25.65002	0.011132	1.09E-11	3.086716
Mtr.38836.1.S1_at	Mtr.38836.1	TC103638 /FEA = mRNA /DEF = weakly similar to UP/Q7XZC4 (Q7XZC4) Albumin 1 precursor, partial (38%)	TC103638	52.2156	42.01571	159.3873	42.96095	0.036607	9.96E-06	3.052485
Mtr.16385.1.S1_s_at	Mtr.16385.1	IMGAG1868.m00028 /FEA = mRNA /DEF = TIR AC135396.30.281 94888 94343 mth2-33o18 Jan. 13, 2005	IMGAG1868.m00028	10.64898	1.522778	32.19086	5.725062	0.003248	1.4E-132	3.022904
Mtr.33192.1.S1_at	Mtr.33192.1	BF645922 /FEA = mRNA /DEF = weakly similar to UP/Q6SQJ0 (Q6SQJ0) NBS-LRR type disease resistance protein Hom-F, partial (2%)	BF645922	20.28828	10.87565	60.92976	7.18335	0.005689	0	3.0032
Mtr.1157.1.S1_s_at	Mtr.1157.1	1544.m00032 /FEA = mRNA /DEF = AC149039.2 10370 11266 mth2-4g23 weakly similar to UP/Q6WAY3 (Q6WAY3) Gag/pol polyprotein	1544.m00032	213.1824	87.58313	636.2443	10.6119	0.001148	0	2.984506
Mtr.17967.1.S1_x_at	Mtr.17967.1	IMGAG1930.m00018 /FEA = mRNA /DEF = protein T2E6.4 [imported] - <i>Arabidopsis thaliana</i> -related AC138015.24.171 100595 100984 mth2-34m6 Jan. 13, 2005	IMGAG1930.m00018	20.25361	0.991312	59.70946	5.97694	0.000352	0	2.948089

TABLE 3-continued

List of probesets down- and up-regulated in transformed hairy roots by more than two-fold and also at a statistically significant level (p-value <5%). Probesets are found at <i>Medicago truncatula</i> Gene Expression Atlas ("MGEA," Benedetto et al., 2008; He et al., 2009).										
Probesets	Transcript ID(Array Design)	Target Description	Representative Public ID	Ave OE-GUS	SD OE-GUS	Ave OE-PAR	SD OE-PAR	PTS	PTA	Ratio (OE-PAR:OE-GUS)
Msa.3055.1.S1_at	Msa.3055.1	iMsa.3055 / TID = Msa.3055.1 / CNT = 1 / FEA = mRNA / THER = ConsEnd / STK = 0 / NOTE = sequence(s) not in UniGene / DEF =	TC60	18.64459	13.70837	54.52178	17.48199	0.048953	5.81E-06	2.924268
Mtr.8651.1.S1_at	Mtr.8651.1	TC100921 / FEA = mRNA / DEF = homologue to UPIQ945Q7 (Q945Q7) Dehydrin-like protein, partial (72%)	TC100921	12.25328	3.563077	35.43201	13.17635	0.042337	1.9E-29	2.891635
Mtr.148.1.S1_s_at	Mtr.148.1	1785.m00048 / FEA = mRNA / DEF = AC155890.1 47822 48796 mth2-49p3	1785.m00048	100.0611	28.76711	288.2107	25.54402	0.001064	0	2.880346
Mtr.13746.1.S1_at	Mtr.13746.1	TC99043 / FEA = mRNA / DEF = weakly similar to UPIQ9F139 (Q9F139) Cytochrome P450, partial (25%)	TC99043	50.91619	7.994512	146.3706	42.7455	0.019072	5.17E-95	2.874736
Mtr.40156.1.S1_at	Mtr.40156.1	TC106633 / FEA = mRNA / DEF = similar to UPIQ8W2E3 (Q8W2E3) 3-hydroxy-3-methylglutaryl coenzyme A, partial (83%)	TC106633	5.88781	1.253098	16.89492	2.715512	0.003106	2.85E-52	2.869474
Mtr.4415.1.S1_s_at	Mtr.4415.1	AJ501932 / FEA = mRNA / DEF = weakly similar to UPIQ43373 (Q43373) Galactose-binding lectin precursor, partial (19%)	AJ501932	691.9708	439.3457	1955.44	329.3917	0.016328	3.06E-11	2.8259
Mtr.11000.1.S1_at	Mtr.11000.1	TC108561 / FEA = mRNA / DEF =	TC108561	14.38511	1.402579	40.35665	12.81938	0.025163	1.1E-225	2.805447
Mtr.12285.1.S1_at	Mtr.12285.1	TC94253 / FEA = mRNA / DEF =	TC94253	416.0914	384.7539	1128.625	136.4191	0.03904	0	2.712445
Mtr.48045.1.S1_at	Mtr.48045.1	1601.m00057 / FEA = mRNA / DEF = AC134824.27 103986 104615 mth2-14a2	1601.m00057	168.9576	22.01792	453.356	141.1259	0.026085	7.3E-111	2.683253
Mtr.22080.1.S1_at	Mtr.22080.1	1582.m00056 / FEA = mRNA / DEF = AC127018.22 115376 121759 mth2-8a13	1582.m00056	5.811889	0.238395	15.34872	5.194527	0.033645	0	2.640918
Mtr.6517.1.S1_at	Mtr.6517.1	BQ147749 / FEA = mRNA / DEF = similar to UPIQ84165 (Q84165) Gray pubescence flavonoid 3'-hydroxylase, partial (49%)	BQ147749	199.134	68.14577	525.2062	26.42525	0.00151	0	2.637451
Mtr.36073.1.S1_s_at	Mtr.36073.1	AJ845987 / FEA = mRNA / DEF = similar to GB/AAA80183.1 606720 RPU12784 lectin { <i>Robinia pseudoacacia</i> }, partial (11%)	AJ845987	2384.764	1247.153	6282.824	506.7705	0.007409	0	2.634569
Mtr.5990.1.S1_s_at	Mtr.5990.1	BG455728 / FEA = mRNA / DEF =	BG455728	13.1366	3.485436	34.51418	12.70297	0.048271	2.32E-26	2.62733
Mtr.40319.1.S1_at	Mtr.40319.1	TC107032 / FEA = mRNA / DEF = weakly similar to UPIQ9ZWP4 (Q9ZWP4) Lectin-related polypeptide, partial (49%)	TC107032	2514.163	1294.344	6595.446	267.2237	0.005891	0	2.623317
Mtr.31903.1.S1_at	Mtr.31903.1	AL385004 / FEA = mRNA / DEF = similar to UPISTEL_RHUV (P00302) Stellacyanin, partial (14%)	AL385004	329.2612	76.9095	844.1129	62.52478	0.000845	0	2.563657
Mtr.31215.1.S1_s_at	Mtr.31215.1	AJ499431 / FEA = mRNA / DEF =	AJ499431	81.09492	37.10519	206.5585	52.22605	0.027479	4.73E-09	2.54712

TABLE 3-continued

List of probesets down- and up-regulated in transformed hairy roots by more than two-fold and also at a statistically significant level (p-value <5%). Probesets are found at <i>Medicago truncatula</i> Gene Expression Atlas ("MGEA," Benedetto et al., 2008; He et al., 2009).										
Probesets	Transcript ID(Array Design)	Target Description	Representative Public ID	Ave OE-GUS	SD OE-GUS	Ave OE-PAR	SD OE-PAR	PTS	PTA	Ratio (OE-PAR:OE-GUS)
Mtr.12742.1.S1_at	Mtr.12742.1	TC95807 /FEA = mRNA /DEF = similar to UP/O49134 (O49134) GAST-like gene product, partial (73%)	TC95807	13.3915	2.590072	33.85925	12.18706	0.046613	1.21E-42	2.528414
Mtr.18705.1.S1_at	Mtr.18705.1	IMGAG1960.m00016 /FEA = mRNA /DEF = Peptidase C1A, papain; Peptidase, eukaryotic cysteine peptidase active site AC139746.15.151.101606 103039	IMGAG1960.m00016	102.9695	49.4787	258.0454	47.81252	0.017486	1.93E-08	2.506039
Mtr.17982.1.S1_s_at	Mtr.17982.1	mh2-1.7b20 Jan. 13, 2005 IMGAG1932.m00012 /FEA = mRNA /DEF = hypothetical protein AC138017.15.111.51242 50808 mh2-613 Jan. 13, 2005	IMGAG1932.m00012	5.95394	0.965889	14.90417	3.109012	0.008894	5.76E-58	2.503244
Mtr.51818.1.S1_at	Mtr.51818.1	IMGAG1896.m00006 /FEA = mRNA /DEF = predicted protein AC136840.24.51 30231 32005 mh2-33n3 Jan. 13, 2005	IMGAG1896.m00006	113.8143	38.82412	281.0649	78.87617	0.03007	8.55E-14	2.469505
Mtr.44634.1.S1_at	Mtr.44634.1	TC97763 /FEA = mRNA /DEF = weakly similar to UP/Q6NLR7 (Q6NLR7) Ar5g04070, partial (53%)	TC97763	36.4022	17.80958	89.61022	20.25625	0.026858	2.28E-07	2.46167
Mtr.9765.1.S1_at	Mtr.9765.1	TC104312 /FEA = mRNA /DEF =	TC104312	81.45997	41.25091	200.0031	34.49291	0.018804	2.64E-09	2.455232
Mtr.17787.1.S1_at	Mtr.17787.1	IMGAG1015.m00001 /FEA = mRNA /DEF = Isopenicillin N synthase; 2OG-Fe(II) oxygenase AC142498.21.11 7699 4521 mh2-24a18 Jan. 13, 2005	IMGAG1015.m00001	10.06593	2.903876	24.64216	1.36213	0.001408	0	2.448075
Mtr.37882.1.S1_at	Mtr.37882.1	TC101626 /FEA = mRNA /DEF = similar to UP/Q687E1 (Q687E1) Nucleotide pyrophosphatase/phosphodiesterase (fragment), complete	TC101626	310.6463	198.6411	746.3512	37.6148	0.020248	0	2.402575
Mtr.4815.1.S1_at	Mtr.4815.1	AL385005 /FEA = mRNA /DEF =	AL385005	911.7991	200.3234	2188.037	193.7633	0.001368	0	2.396692
Mtr.15436.1.S1_at	Mtr.15436.1	IMGAG1786.m00019 /FEA = mRNA /DEF = 2OG-Fe(II) oxygenase; Immunoglobulin/major histocompatibility complex	IMGAG1786.m00019	254.5841	98.97065	600.6536	30.63402	0.004435	0	2.359352
Mtr.25672.1.S1_a_at	Mtr.25672.1	AC125478.13.191.98375 97104 mh2-31i19 Jan. 13, 2005 1446.m00048 /FEA = mRNA /DEF = AC146752.23 87430 86695 mh2-6244	1446.m00048	113.0598	26.58139	266.0491	13.32507	0.000876	0	2.353172
Mtr.43296.1.S1_at	Mtr.43296.1	TC95005 /FEA = mRNA /DEF =	TC95005	13.34978	7.401407	31.26966	4.316036	0.022306	6.41E-13	2.342335
Mtr.32965.1.S1_at	Mtr.32965.1	BF635325 /FEA = mRNA /DEF = similar to UP/Q9ZSP7 (Q9ZSP7) Cytochrome b5 DIF-F, partial (36%)	BF635325	181.4723	36.40511	422.1875	96.95071	0.015786	2.28E-30	2.326457
Mtr.41019.1.S1_at	Mtr.41019.1	TC108557 /FEA = mRNA /DEF = similar to UP/Q39449 (Q39449) Specific tissue protein 1, partial (93%)	TC108557	422.5297	178.6819	981.0658	109.6544	0.009922	0	2.321886

TABLE 3-continued

Probesets	Transcript ID(Array Design)	Target Description	Representative Public ID	Ave OE- GUS	SD OE- GUS	Ave OE- PAR	SD OE- PAR	PTS	PTA	Ratio (OE- PAR:OE- GUS)
Mtr.48723.1.S1_at	Mtr.48723.1	IMGAG11156.m00003 /FEA = mRNA /DEF = NPH3; B7B/POZ AC147002.20.21 21589 19459 mth2-151m16 Jan. 13, 2005 TC104797 /FEA = mRNA /DEF = weakly similar to UP/Q9LQ75 (Q9LQ75)	IMGAG11156.m00003	114.5791	43.79727	265.6709	43.83067	0.01344	2.3E-09	2.318669
Mtr.9894.1.S1_at	Mtr.9894.1	TIN6.22 protein, partial (48%) CX525345 /FEA = mRNA /DEF = TC107430 /FEA = mRNA /DEF = weakly similar to UP/NL2_PRUAR (P82353) Nonspecific lipid-transfer protein 2 (LTP 2), partial (97%)	TC104797	382.3435	89.5521	868.8384	157.6059	0.009672	4.99E-21	2.272403
Mtr.3133.1.S1_at	Mtr.3133.1	1631.m00034 /FEA = mRNA /DEF = AC138465.20 10086 8601 mth2-23h19 weakly similar to	CX525345	55.87685	23.32709	126.4847	15.5516	0.012042	3.77E-15	2.263634
Mtr.10630.1.S1_at	Mtr.10630.1	TAIR gene: 3437446-GOpep. 168409. m02443 bHLH protein family contains Pfam profile: PF00010	TC107430	336.2662	105.3783	761.1442	59.20414	0.00368	0	2.263517
Mtr.47758.1.S1_at	Mtr.47758.1	TC105266 /FEA = mRNA /DEF = IMGAG1115.m00011 /FEA = mRNA /DEF = Naringenin-chalcone synthase; Type III polyketide synthase AC146683.9.101 54170 52902 mth2-179n10 Jan. 13, 2005	1631.m00034	46.18555	10.93704	104.5183	8.215752	0.001791	0	2.26301
Mtr.29531.1.S1_at	Mtr.29531.1	BI312112 /FEA = mRNA /DEF = similar to UP/Q8LJS8 (Q8LJS8) Homeodomain protein GhHOX1, partial (27%)	TC105266	65.9136	32.72179	148.0582	11.8568	0.014999	0	2.246247
Mtr.14428.1.S1_x_at	Mtr.14428.1	TC101400 /FEA = mRNA /DEF = similar to UP/Q6A151 (Q6A151) Peripheral-type benzodiazepine receptor, partial (25%)	IMGAG1115.m00011	54.98663	6.632739	122.9121	24.1427	0.009315	2.14E-70	2.235309
Mtr.28737.1.S1_at	Mtr.28737.1	IMGAG1831.m00012 /FEA = mRNA /DEF = Copper/Zinc superoxide dismutase AC130801.16.121 78670	BI312112	174.1705	52.26805	385.1184	60.70735	0.010331	2.74E-12	2.211157
Mtr.8790.1.S1_at	Mtr.8790.1	77054 mth2-12p19 Jan. 13, 2005 IMGAG1762.m00015 /FEA = mRNA /DEF = Basic helix-loop-helix dimerisation region bHLH; Helix-loop-helix DNA-binding AC124214.8.141 73702 74845 mth2-36a23 Jan. 13, 2005	TC101400	128.399	29.50636	283.73	22.6213	0.001935	0	2.209753
Mtr.16601.1.S1_at	Mtr.16601.1	TC108588 /FEA = mRNA /DEF = IMGAG1220.m00020 /FEA = mRNA /DEF = hypothetical protein AC148758.19.191 94204 93893 mth2-50117 Jan. 13, 2005	IMGAG1831.m00012	3596.316	251.4687	7918.753	746.7478	0.000685	0	2.201907
Mtr.14760.1.S1_at	Mtr.14760.1	TC110723 /FEA = mRNA /DEF =	IMGAG1762.m00015	73.3436	36.87561	161.3223	30.27665	0.033096	4.83E-07	2.199542
Mtr.11011.1.S1_at	Mtr.11011.1		TC108588	64.67045	12.32351	141.6272	17.2181	0.003254	2.89E-27	2.189983
Mtr.20511.1.S1_s_at	Mtr.20511.1		IMGAG1220.m00020	18.52573	5.592439	40.50186	3.917321	0.005075	0	2.186248
Mtr.35669.1.S1_at	Mtr.35669.1		TC110723	14.0884	7.023	30.73013	4.783246	0.027474	1.68E-09	2.181236

TABLE 3-continued

List of probesets down- and up-regulated in transformed hairy roots by more than two-fold and also at a statistically significant level (p-value <5%). Probesets are found at <i>Medicago truncatula</i> Gene Expression Atlas ("MGEA," Benedetto et al., 2008; He et al., 2009).										
Probesets	Transcript ID(Array Design)	Target Description	Representative Public ID	Ave OE-GUS	SD OE-GUS	Ave OE-PAR	SD OE-PAR	PTS	PTA	Ratio (OE-PAR:OE-GUS)
Mtr.46188.1.S1_x_at	Mtr.46188.1	IMGAG1140.m00023 /FEA = mRNA /DEF = hypothetical protein AC146793.7.221 111595 111440 mth2-10p9 Jan. 13, 2005	IMGAG1140.m00023	10.61773	2.063498	23.15905	1.747313	0.001303	0	2.181168
Mtr.38138.1.S1_at	Mtr.38138.1	TC102170 /FEA = mRNA /DEF = weakly similar to UP/Q9LH70 (Q9LH70) Gb/AAD22996.1, partial (66%)	TC102170	23.32823	3.339804	50.80832	11.62925	0.017048	4.39E-46	2.177976
Mtr.18535.1.S1_at	Mtr.18535.1	IMGAG1954.m00017 /FEA = mRNA /DEF = conserved hypothetical protein AC139601.8.171 104858 102948 mth2-8h11 Jan. 13, 2005	IMGAG1954.m00017	17.22274	3.896279	37.29194	8.072006	0.017869	4.6E-19	2.165274
Mtr.43089.1.S1_at	Mtr.43089.1	TC94508 /FEA = mRNA /DEF = similar to UP/Q9FDY1 (Q9FDY1) Seed maturation protein LEA 4, partial (45%)	TC94508	472.5886	230.4404	1020.365	199.9903	0.035889	2.09E-06	2.159098
Msa.1900.1.S1_at	Msa.1900.1	iMsa.1900 /TID = Msa.1900.1 /CNT = 1 /FEA = mRNA /TIER = ConsEnd /STK = 0 /NOTE = sequence(s) not in UniGene /DEF =	TC336	2557.748	91.76779	5511.223	289.7219	7.3E-05	0	2.154717
Mtr.35816.1.S1_at	Mtr.35816.1	TC95830 /FEA = mRNA /DEF = homologue to UP/MCT1_HUMAN (P23946) Chymase precursor (Mast cell protease I), partial (6%)	TC95830	1746.035	591.5726	3758.277	504.1642	0.010956	4.74E-12	2.152463
Mtr.31448.1.S1_x_at	Mtr.31448.1	AJ848642 /FEA = mRNA /DEF = similar to UP/NLA_LOTIA (P39869) Nitrate reductase [NADH] (NR), partial (8%)	AJ848642	6.731572	1.044538	14.46105	4.050463	0.032883	1.32E-37	2.148243
Mtr.43393.1.S1_at	Mtr.43393.1	TC95204 /FEA = mRNA /DEF = weakly similar to UP/NAS_LYCES (Q9XG17) Nicotianamine synthase (S-adenosyl-L-methionine:S-adenosyl-L-methionine:adenosyl-methionine 3-amino-3-carboxypropyltransferase) (Chloronerva), partial (84%)	TC95204	1014.085	86.40734	2177.974	171.9263	0.000469	0	2.147724
Mtr.8505.1.S1_at	Mtr.8505.1	TC100418 /FEA = mRNA /DEF = similar to UP/Q06765 (Q06765) ADR6 protein (Sal15-4a protein), partial (68%)	TC100418	3038.322	492.151	6501.841	560.1494	0.001296	0	2.139945
Mtr.45103.1.S1_at	Mtr.45103.1	TC98800 /FEA = mRNA /DEF = similar to UP/Q8S3C2 (Q8S3C2) GTP cyclohydrolase I, partial (18%)	TC98800	75.21676	13.28341	160.2015	13.62552	0.001504	0	2.129864
Mtr.5804.1.S1_at	Mtr.5804.1	BF650415 /FEA = mRNA /DEF = weakly similar to Gb/AO44030.1/28466843/IBT004764 Atg56220 { <i>Arabidopsis thaliana</i> }, partial (47%)	BF650415	19.10882	6.124257	40.45365	4.844521	0.009074	2.33E-14	2.117015

TABLE 3-continued

Probesets		Transcript ID(Array Design)	Target Description	Representative Public ID	Ave OE-GUS	SD OE-GUS	Ave OE-PAR	SD OE-PAR	PTS	PTA	Ratio (OE-PAR:OE-GUS)
Mtr.27451.1.S1_at	Mtr.16363.1.S1_s_at	Mtr.27451.1	BE124481 /FEA = mRNA /DEF = IMGAG1868.m00002 /FEA = mRNA /DEF = LQGC hypothetical protein AC135396.30.21 8440 9117 mth2-33o18 Jan. 13, 2005	BE124481 IMGAG1868.m00002	43.56527 139.0985	14.58105 67.29957	92.0503 293.1822	4.436768 5.736049	0.005293 0.016801	0 0	2.112928 2.107731
Msa.2939.1.S1_at		Msa.2939.1	iMsa.2939 /TID = Msa.2939.1 /CNT = 1 /FEA = mRNA /TIER = ConsEnd /STK = 0 /NOTE = sequence(s) not in UniGene /DEF =	TC109	119.868	36.61586	251.9845	21.27225	0.005678	0	2.102183
Mtr.40711.1.S1_at		Mtr.40711.1	TC107889 /FEA = mRNA /DEF = weakly similar to UP/Q43583 (Q43583) Hsr201 protein, partial (75%)	TC107889	906.4601	70.64078	1891.396	100.0925	0.000154	0	2.086574
Mtr.9728.1.S1_at		Mtr.9728.1	TC104194 /FEA = mRNA /DEF = similar to GB/AAL10495.1115983791/AY056804 AT5g39660/MU24_130 { <i>Arabidopsis thaliana</i> }; partial (16%)	TC104194	47.34348	21.52288	98.76909	7.435708	0.01737	0	2.086224
Mtr.32011.1.S1_at	Mtr.27024.1.S1_at	Mtr.3201.1	AL389071 /FEA = mRNA /DEF = AL389774 /FEA = mRNA /DEF = 1654.m00057 /FEA = mRNA /DEF = AC144730.17 96684 96091 mth2-5j23 weakly similar to UP/Q7XZC5 (Q7XZC5) Albumin 1 precursor	AL389071 AL389774 1654.m00057	52.39482 25.91605 2611.659	12.29109 5.150654 849.4693	109.1084 53.77898 5398.906	23.90432 8.085224 611.11	0.021684 0.007312 0.00993	1.33E-15 7.28E-21 2.89E-15	2.082427 2.075123 2.067232
Mtr.31070.1.S1_s_at		Mtr.31070.1	GB/AAL05900.1115777879/AY05100 AT3g15640/MSJ11_4 { <i>Arabidopsis thaliana</i> }; partial (53%)	AA660761	347.1108	20.11124	716.2835	22.5441	2.95E-05	0	2.063559
Mtr.39897.1.S1_at		Mtr.39897.1	TC105988 /FEA = mRNA /DEF = similar to UP/P93697 (P93697) CPRD12 protein, partial (61%)	TC105988	12.76636	2.427718	26.33559	7.758552	0.044517	3.63E-22	2.06289
Mtr.11130.1.S1_at	Mtr.12550.1.S1_at	Mtr.11130.1	TC108984 /FEA = mRNA /DEF = TC95205 /FEA = mRNA /DEF = weakly similar to UP/Q8L5A7 (Q8L5A7) Steroid sulfotransferase-like protein (At5g07010), partial (70%)	TC108984 TC95205	37.58262 860.1017	19.77651 388.5234	77.48235 1769.983	10.32217 375.5879	0.036295 0.043401	2.15E-11 2.72E-05	2.061654 2.057877
Mtr.42071.1.S1_at		Mtr.42071.1	TC110696 /FEA = mRNA /DEF = similar to UP/Q8VYU3 (Q8VYU3) GTP cyclohydrolase I, partial (47%)	TC110696	71.43369	14.03497	146.9395	30.793	0.018077	1.18E-20	2.057006
Mtr.39846.1.S1_at		Mtr.39846.1	TC105872 /FEA = mRNA /DEF = similar to UP/Q8W4Y8 (Q8W4Y8) Trypsin/chymotrypsin inhibitor (Fragment), partial (14%)	TC105872	23.815	9.487137	48.84013	5.45748	0.016674	2E-15	2.050814

TABLE 3-continued

List of probesets down- and up-regulated in transformed hairy roots by more than two-fold and also at a statistically significant level (p-value <5%). Probesets are found at <i>Medicago truncatula</i> Gene Expression Atlas ("MGEA," Benedito et al., 2008; He et al., 2009).										
Probesets	Transcript ID(Array Design)	Target Description	Representative Public ID	Ave OE-GUS	SD OE-GUS	Ave OE-PAR	SD OE-PAR	PTS	PTA	Ratio (OE-PAR:OE-GUS)
Mtr.40827.1.S1_at	Mtr.40827.1	TC108133 /FEA = mRNA /DEF = weakly similar to GB/CAA66109.3/48426429/CANST2PRO specific tissue protein 2 { <i>Cicer arietinum</i> }, partial (70%)	TC108133	747.7229	259.3841	1533.206	284.0401	0.02408	1.56E-07	2.0505
Mtr.44300.1.S1_at	Mtr.44300.1	TC97086 /FEA = mRNA /DEF = similar to UP/Q9ZR88 (Q9ZR88) Bifunctional nuclease (Fragment), partial (93%)	TC97086	75.54789	34.64619	154.9086	9.188523	0.018541	0	2.050469
Mtr.37042.1.S1_at	Mtr.37042.1	TC110897 /FEA = mRNA /DEF = 1631.m00057 /FEA = mRNA /DEF = AC138465.20.116022.117716 mth2-23h19 weakly similar to UP/Q8H612 (Q8H612)	TC110897 1631.m00057	20.83234 94.99832	5.381611 32.33108	42.64093 194.2188	1.777659 33.78853	0.002633 0.0213	0 1.06E-07	2.046862 2.044444
Mtr.49527.1.S1_at	Mtr.49527.1	containing protein-like IMGAG1106.m00022 /FEA = mRNA /DEF = Lipolytic enzyme, G-D-S-L AC146586.2.221.91053.88472 mth2-71m12 Jan. 13, 2005	IMGAG1106.m00022	10.90944	2.480131	22.12558	3.280984	0.009148	4.76E-15	2.028113
Mtr.41946.1.S1_at	Mtr.41946.1	TC110438 /FEA = mRNA /DEF = similar to GB/AAL05900.1115777879.AY055100 AT3g15640/MSJ11_4 { <i>Arabidopsis thaliana</i> }, partial (67%)	TC110438	614.7155	63.04668	1246.147	39.46543	0.000124	0	2.027193
Mtr.11192.1.S1_at	Mtr.11192.1	TC109165 /FEA = mRNA /DEF = similar to UP/Q9FUK3 (Q9FUK3) Cytochrome-regulated kinase 1, partial (29%)	TC109165	51.64972	15.81417	104.5602	15.95759	0.015109	6.83E-09	2.024409
Mtr.24497.1.S1_at	Mtr.24497.1	1744.m00038 /FEA = mRNA /DEF = AC151668.21.49824.44618 mth2-6e22 weakly similar to TIGR_Ath1/At1gl4570-GOpep.168408.m01564 expressed protein, partial (28%)	1744.m00038	26.87012	7.203024	53.78477	6.803399	0.009274	7.28E-12	2.001657
Mtr.28447.1.S1_at	Mtr.28447.1	BG645848 /FEA = mRNA /DEF = TC110250 /FEA = mRNA /DEF = similar to UP/Q9MA26 (Q9MA26) TSE21.7, partial (14%)	BG645848 TC110250	29.61205 27.60078	2.906507 4.98102	59.24899 55.2228	11.91676 8.326096	0.013863 0.007867	8.33E-70 7.62E-22	2.000841 2.000769
Mtr.23572.1.S1_at	Mtr.23572.1	1681.m00026 /FEA = mRNA /DEF = AC146750.20.21226.20705 mth2-16e6 similar to UP/P93713 (P93713) PEThy; ZPT2-5	1681.m00026	108.7813	33.28696	54.01083	6.087249	0.048641	9.32E-55	0.496508
Mtr.45131.1.S1_at	Mtr.45131.1	TC98879 /FEA = mRNA /DEF = similar to UP/Q9FKJ9 (Q9FKJ9) Gb/AAF24606.1, partial (17%)	TC98879	36.80421	7.765868	18.20608	3.79032	0.020337	1.92E-17	0.494674

TABLE 3-continued

Probesets	Transcript ID(Array Design)	Target Description	Representative Public ID	Ave OE-		SD OE-		Ave OE-		SD OE-		PTS	PTA	Ratio (OE-PAR:OE-GUS)
				GUS		GUS		PAR		PAR				
Mtr.33150.1.S1_s_at	Mtr.33150.1	BF644297 /FEA = mRNA /DEF = similar to UP/Q8S902 (Q8S902) Syringolide-induced protein 19-1-5, partial (25%)	BF644297	212.6908		66.46657		105.0397		9.379603		0.049933	6.19E-88	0.493861
Mtr.33148.1.S1_at	Mtr.33148.1	BF644261 /FEA = mRNA /DEF = homologue to UP/O22247 (O22247) Small nuclear ribonucleoprotein-like protein (A12647640), partial (87%)	BF644261	74.39456		10.79339		36.49784		4.716791		0.005082	5.06E-44	0.490598
Mtr.42263.1.S1_at	Mtr.42263.1	TC111084 /FEA = mRNA /DEF = similar to UP/Q9ZTM8 (Q9ZTM8) PGPS/D12, partial (47%)	TC111084	345.4222		71.55666		169.1052		71.35791		0.039087	1.87E-05	0.489561
Mtr.6648.1.S1_s_at	Mtr.6648.1	BQ153446 /FEA = mRNA /DEF = similar to UP/Q8GTJ0 (Q8GTJ0) Xyloglucan endotransglycosylase, partial (30%)	BQ153446	481.3641		109.1397		234.7549		21.66545		0.018479	1.6E-86	0.487687
Msa.1604.1.S1_at	Msa.1604.1	iMsa.1604 /TID = Msa.1604.1 /CNT = 1 /FEA = mRNA /TIER = ConsEnd /STK = 0 /NOTE = sequence(s) not in UniGene /DEF =	TC151	1184.941		367.0642		576.7456		91.10772		0.049547	6.39E-31	0.48673
Mtr.48557.1.S1_at	Mtr.48557.1	IMGAG1164.m00004 /FEA = mRNA /DEF = Protein of unknown function DUF588; Plant integral membrane protein AC147364.7.31 14158 12772 mth2-68g24 Jan. 13, 2005	IMGAG1164.m00004	323.4778		16.86926		156.4709		21.13107		0.000433	0	0.483715
Mtr.12560.1.S1_at	Mtr.12560.1	TC95232 /FEA = mRNA /DEF = similar to UP/GTX6_S0YBN (P32110) Probable glutathione S-transferase (Heat shock protein 26A) (G2-4), complete	TC95232	467.0138		89.42901		225.3946		7.236743		0.009558	0	0.482629
Mtr.42263.1.S1_s_at	Mtr.42263.1	TC111084 /FEA = mRNA /DEF = similar to UP/Q9ZTM8 (Q9ZTM8) PGPS/D12, partial (47%)	TC111084	245.3696		27.9992		118.1749		33.31503		0.007168	3.55E-15	0.48162
Mtr.10522.1.S1_s_at	Mtr.10522.1	TC107029 /FEA = mRNA /DEF = similar to PIRID96538ID96538 cytosolic tRNA-Ala synthetase [imported] - Arabidopsis thaliana {Arabidopsis thaliana;}, partial (33%)	TC107029	98.24196		20.28132		47.11848		5.335859		0.013452	7.58E-62	0.479617
Mtr.48743.1.S1_at	Mtr.48743.1	IMGAG1155.m00004 /FEA = mRNA /DEF = Ribonuclease T2 AC146971.12.41 23294 21472 mth2-128d1 Jan. 13, 2005	IMGAG1155.m00004	35.44762		9.171154		16.60698		3.220422		0.028377	3.94E-24	0.468494
Mtr.8517.1.S1_at	Mtr.8517.1	TC100462 /FEA = mRNA /DEF = similar to UP/MTD_FRAAN (Q9ZRF1) Probable mannitol dehydrogenase (NAD-dependent mannitol dehydrogenase), partial (98%)	TC100462	514.6957		128.2066		240.2763		6.400827		0.020785	0	0.466832
Mtr.19456.1.S1_s_at	Mtr.19456.1	IMGAG1178.m00016 /FEA = mRNA /DEF = AAA ATPase, central region	IMGAG1178.m00016	93.59327		25.71178		43.12689		4.928968		0.028867	2.29E-70	0.460791

TABLE 3-continued

Probesets	Transcript ID(Array Design)	Target Description	Representative Public ID	Ave OE-		SD OE-		Ave OE-		SD OE-		PTS	PTA	Ratio (OE-PAR:OE-GUS)
				GUS	PAR	GUS	PAR	GUS	PAR	GUS	PAR			
Mtr.26842.1.S1_at Msa.509.1.S1_at	Mtr.26842.1 Msa.509.1	AC147498.14.151 61.265 62827 mth2-6f18 Jan. 13, 2005 AJ845621 /FEA = mRNA /DEF = iMsa.509 /TID = Msa.509.1 /CNT = 1 /FEA = mRNA /TIER = ConsEnd /STK = 0 /NOTE = sequence(s) not in UniGene	AJ845621 50319249	539.8633 262.3813	247.4114 120.2051	134.4481 50.30794	77.44588 2.851212	0.030944 0.008119	6.13E-11 0	0.458285 0.458131				
Mtr.4438.1.S1_at	Mtr.4438.1	AI503481 /FEA = mRNA /DEF = similar to UP/Q6RVV4 (Q6RVV4) Short-chain dehydrogenase Tic32, partial (26%)	AJ503481	30.73882	13.94658	6.215417	5.988667	0.028049	1.19E-06	0.453712				
Mtr.10758.1.S1_at Mtr.34114.1.S1_s_at	Mtr.10758.1 Mtr.34114.1	TC107813 /FEA = mRNA /DEF = BQ138448 /FEA = mRNA /DEF = similar to UP/Q39450 (Q39450) Pathogenesis related protein, complete	TC107813 BQ138448	735.6056 766.457	327.7808 339.3063	154.1225 236.7585	76.00594 34.32268	0.014726 0.036483	1.49E-20 4.7E-103	0.445593 0.442695				
Mtr.45232.1.S1_at	Mtr.45232.1	TC99118 /FEA = mRNA /DEF = similar to UP/DR2A_ARATH (O82132) Dehydration responsive element binding protein 2A (DREB2A protein), partial (23%)	TC99118	34.86944	15.08662	10.9945	3.861679	0.042371	7.12E-19	0.43266				
Mtr.50075.1.S1_s_at	Mtr.50075.1	IMGAG1986.m00012 /FEA = mRNA /DEF = RmlC-like cupin; Germarin; Cupin; Cupin region AC140721.15.111 62212 61323 mth2-16c16 Jan. 13, 2005	IMGAG1986.m00012	77.37295	33.08377	26.95238	2.74053	0.04727	2.1E-172	0.427588				
Mtr.8990.1.S1_at	Mtr.8990.1	TC102027 /FEA = mRNA /DEF = homologue to UP/Q9AUH7 (Q9AUH7) UVI1, partial (79%)	TC102027	2077.807	883.6478	721.2363	53.60517	0.045935	0	0.425279				
Mtr.37415.1.S1_s_at	Mtr.37415.1	TC100611 /FEA = mRNA /DEF = similar to UP/Q9SE03 (Q9SE03) Copper chaperone homolog CCH, partial (82%)	TC100611	9217.674	3862.131	691.6444	227.2631	0.000219	0	0.418992				
Mtr.14224.1.S1_at	Mtr.14224.1	IMGAG1216.m00002 /FEA = mRNA /DEF = Proteinase inhibitor I13, potato inhibitor IAC148487.14.21 8524 8228 mth2-57f20 Jan. 13, 2005	IMGAG1216.m00002	1888.532	786.7926	386.4314	169.0794	0.010625	1.53E-29	0.416616				
Mtr.44470.1.S1_at	Mtr.44470.1	TC97425 /FEA = mRNA /DEF = weakly similar to UP/Q9LIR0 (Q9LIR0) Arabidopsis thaliana genomic DNA, chromosome 3, BAC clone: F14O13, partial (7%)	TC97425	67.81564	28.13261	22.79712	5.262464	0.042485	5.5E-39	0.41484				
Mtr.26833.1.S1_at Msa.2910.1.S1_at	Mtr.26833.1 Msa.2910.1	AI503813 /FEA = mRNA /DEF = iMsa.2910 /TID = Msa.2910.1 /CNT = 1 /FEA = mRNA /TIER = ConsEnd /STK = 0 /NOTE = sequence(s) not in UniGene	AJ503813 gi15353555.gb U13709.1 MSU13709	124.3928 2750.135	49.61036 1090.065	7.436086 921.0257	9.613204 190.4528	0.000439 0.037762	0 1.69E-51	0.39882 0.396368				
Mtr.23272.1.S1_at	Mtr.23272.1	1663.m00036 /FEA = mRNA /DEF = AC145202.17 61879 62690 mth2-15e9 weakly similar to UP/Q8LNY0	1663.m00036	632.6005	243.1869	198.7635	48.40887	0.030017	3.99E-44	0.384424				

TABLE 3-continued

List of probesets down- and up-regulated in transformed hairy roots by more than two-fold and also at a statistically significant level (p-value <5%). Probesets are found at <i>Medicago truncatula</i> Gene Expression Atlas ("MtGEA," Benedito et al., 2008; He et al., 2009).										
Probesets	Transcript ID(Array Design)	Target Description	Representative Public ID	Ave OE-GUS	SD OE-GUS	Ave OE-PAR	SD OE-PAR	PTS	PTA	Ratio (OE-PAR:OE-GUS)
(Q8LNY0) Protease inhibitor 2 (Fragment)										
Mtr.43157.1.S1_at	Mtr.43157.1	TC94674 /FEA = mRNA /DEF = homologue to GIB/AB49302.1 1872517 ATU85244 alternative oxidase (<i>Arabidopsis thaliana</i>);, partial (90%) similar to UP/Q6YI95 (Q6YI95) O-methyltransferase, partial (79%) IMGAGI1004.m00003 /FEA = mRNA /DEF = Oligopeptide transporter OPT superfamily AC141323.7.31 12365 8745 mth2-6a23 Jan. 13, 2005	TC94674	1247.775	434.8176	472.6399	175.6558	0.045796	2.12E-14	0.378786
Mtr.40504.1.S1_at	Mtr.40504.1	TC107427 /FEA = mRNA /DEF = weakly similar to UP/Q6YI95 (Q6YI95) O-methyltransferase, partial (79%) IMGAGI1004.m00003 /FEA = mRNA /DEF = Oligopeptide transporter OPT superfamily AC141323.7.31 12365 8745 mth2-6a23 Jan. 13, 2005	TC107427	1179.124	406.0342	440.4643	207.0652	0.048464	6.46E-10	0.373552
Mtr.14430.1.S1_at	Mtr.14430.1	IMGAGI1004.m00003 /FEA = mRNA /DEF = Oligopeptide transporter OPT superfamily AC141323.7.31 12365 8745 mth2-6a23 Jan. 13, 2005	IMGAGI1004.m00003	120.4673	21.97937	44.64807	5.612255	0.004425	4.3E-121	0.370624
Mtr.50074.1.S1_at	Mtr.50074.1	IMGAGI986.m00013 /FEA = mRNA /DEF = RmlC-like cupin; Germin; Cupin; Cupin region AC140721.15.121 64859 65757 mth2-16c16 Jan. 13, 2005	IMGAGI986.m00013	16.04955	4.865213	5.848582	2.286598	0.030309	1.1E-14	0.364408
Mtr.32209.1.S1_at	Mtr.32209.1	AW684842 /FEA = mRNA /DEF = homologue to UP/Q7KRX2 (Q7KRX2) CG33103-PA isoform A, partial (0%)	AW684842	37.41163	4.765853	13.37813	4.336354	0.002956	0	0.357593
Mtr.10662.1.S1_at	Mtr.10662.1	TC107529 /FEA = mRNA /DEF = similar to UP/HS2M_PEA (P46254) Heat shock 22 kDa protein, mitochondrial precursor, partial (95%)	TC107529	1199.274	467.3532	395.7445	17.54732	0.040906	0	0.329987
Mtr.43158.1.S1_s_at	Mtr.43158.1	TC94675 /FEA = mRNA /DEF = similar to UP/AOX1_TOBAC (Q41224) Alternative oxidase 1, mitochondrial precursor, partial (32%)	TC94675	419.3234	130.9232	137.0082	30.37405	0.021998	2.6E-58	0.326736
Mtr.8550.1.S1_s_at	Mtr.8550.1	TC100587 /FEA = mRNA /DEF = similar to UP/ILGB2_VICFA (P93848) Leghemoglobin 29 (V1b29), complete	TC100587	32.55662	5.816939	10.20394	1.414009	0.002944	4.7E-165	0.313421
Mtr.13532.1.S1_at	Mtr.13532.1	TC98300 /FEA = mRNA /DEF = similar to UP/Q9XFX1 (Q9XFX1) Cytochrome P450, partial (46%)	TC98300	133.1686	55.58377	39.35262	8.602147	0.044607	1.38E-79	0.29551
Mtr.8284.1.S1_s_at	Mtr.8284.1	MTUCP49TVB /FEA = mRNA /DEF = similar to UP/ILGB4_MEDSA (P28010) Leghemoglobin, partial (42%)	MTUCP49TVB	65.59502	2.387178	19.35398	4.369956	8.74E-05	0	0.295053
Mtr.14692.1.S1_at	Mtr.14692.1	IMGAGI758.m00012 /FEA = mRNA /DEF = Helix-turn-helix, Fis-type; Transcription factor, K-box	IMGAGI758.m00012	295.5592	119.5951	86.20861	15.39617	0.039662	1.2E-122	0.29168
Mtr.25451.1.S1_at	Mtr.25451.1	AC123898.40.121 63530 62038 mth2-31m6 Jan. 13, 2005	1417.m00057	329.7007	119.1834	95.56038	8.914978	0.027449	0	0.28984
		/DEF = AC125476.30 106640 113980								

TABLE 3-continued

List of probesets down- and up-regulated in transformed hairy roots by more than two-fold and also at a statistically significant level (p-value <5%). Probesets are found at <i>Medicago truncatula</i> Gene Expression Atlas ("MtGEA," Benedetto et al., 2008; He et al., 2009).										
Probesets	Transcript ID(Array Design)	Target Description	Representative Public ID	Ave OE-GUS	SD OE-GUS	Ave OE-PAR	SD OE-PAR	PTS	PTA	Ratio (OE-PAR:OE-GUS)
Mtr:43877.1.S1_at	Mtr:43877.1	mtb2-10e13 similar to TIGR_Ath1/At1g50200-GOpep.168408. m05157 alanine-tRNA ligase-related similar to alanine-tRNA ligase, partial (39%)	TC96232	211.2336	40.95913	59.3035	18.96201	0.004312	8.64E-44	0.280748
Mtr:29279.1.S1_at	Mtr:29279.1	PIR[T48875/T48875 copper transport protein [imported]] - <i>Arabidopsis thaliana</i> { <i>Arabidopsis thaliana</i> ;}, partial (46%)	CB892810	64.71457	26.70458	18.15443	10.06084	0.047539	1.1E-15	0.280531
Mtr:37751.1.S1_at	Mtr:37751.1	TC101337 /FEA = mRNA /DEF = similar to UP/Q96573 (Q96573) Lipoxigenase, partial (30%)	TC101337	301.8951	88.13819	83.13192	12.38967	0.013083	2.1E-205	0.275567
Mtr:44545.1.S1_at	Mtr:44545.1	TC97577 /FEA = mRNA /DEF = BQ152604 /FEA = mRNA /DEF = similar to UP/Q8LNY0 (Q8LNY0) Protease inhibitor 2 (Fragment), partial (75%)	TC97577 BQ152604	410.4233 994.945	56.30856 465.0277	111.1992 243.6699	8.089142 6.926287	0.000805 0.048916	0 0	0.270938 0.244908
Mtr:8297.1.S1_at	Mtr:8297.1	MTVAU52TV /FEA = mRNA /DEF = 1741.m00060 /FEA = mRNA /DEF = AC151525.10 132154 132664	MTVAU52TV 1741.m00060	86.00236 166.1294	32.18278 32.39907	20.82475 39.748	2.808697 26.18176	0.02502 0.006276	0 6.23E-17	0.242142 0.239259
Mtr:43609.1.S1_at	Mtr:43609.1	mtb2-77j8 TC95697 /FEA = mRNA /DEF = weakly similar to UP/Q6K3E9 (Q6K3E9) F-box family protein-like, partial (35%)	TC95697	255.4591	118.2874	56.74687	6.308619	0.043873	0	0.222137
Mtr:51040.1.S1_s_at	Mtr:51040.1	IMGAGI729.m00012 /FEA = mRNA /DEF = Cytochrome b-245, heavy chain; Phenol hydroxylase reductase; Ferric reductase-like transmembrane component AC121237.19.111 36606 39780 mth2-22g11 Jan. 13, 2005	IMGAGI729.m00012	389.5528	56.34564	84.55705	9.993006	0.000765	0	0.217062
Mtr:13623.1.S1_at	Mtr:13623.1	TC98573 /FEA = mRNA /DEF = 1417.m00057 /FEA = mRNA /DEF = AC125476.30 106640 113980	TC98573 1417.m00057	77.63739 151.5841	11.60822 61.32089	16.31947 31.20105	2.136159 4.668218	0.000845 0.027518	0 0	0.210201 0.205833
Mtr:25451.1.S1_s_at	Mtr:25451.1	mtb2-10e13 similar to TIGR_Ath1/At1g50200-GOpep.168408. m05157 alanine-tRNA ligase-related similar to alanine-tRNA ligase, partial (39%)								

TABLE 3-continued

List of probesets down- and up-regulated in transformed hairy roots by more than two-fold and also at a statistically significant level (p-value <5%). Probesets are found at <i>Medicago truncatula</i> Gene Expression Atlas ("MGEA;" Benedito et al., 2008; He et al., 2009).										
Probesets	Transcript ID(Array Design)	Target Description	Representative Public ID	Ave OE-GUS	SD OE-GUS	Ave OE-PAR	SD OE-PAR	PTS	PTA	Ratio (OE-PAR:OE-GUS)
Mtr.27753.1.S1_at	Mtr.27753.1	BE998400 /FEA = mRNA /DEF = similar to UP/Q96569 (Q96569) L-lactate dehydrogenase, partial (62%)	BE998400	195.7362	72.49264	39.69109	0.06186	0.020326	0	0.202778
Mtr.44349.1.S1_at	Mtr.44349.1	TC97188 /FEA = mRNA /DEF = UP/Q9AWG7 (Q9AWG7) Zinc transporter, partial (96%)	TC97188	1115.947	89.81108	219.0508	4.170486	6.58E-05	0	0.196291
Mtr.23266.1.S1_at	Mtr.23266.1	1663.m00030 /FEA = mRNA /DEF = AC145202.17 44559 44888 mth2-15e9 weakly similar to UP/Q6Y6Y6 (Q6Y6Y6) Protease inhibitor	1663.m00030	438.6837	214.4506	79.15013	2.30515	0.043956	0	0.180426
Mtr.28310.1.S1_at	Mtr.28310.1	BG588509 /FEA = mRNA /DEF = similar to PDB1ISCH_A16331301ISCH_A Chain A, Peanut Peroxidase, { <i>Arachis hypogaea</i> }, partial (68%)	BG588509	152.8108	25.76567	27.07278	1.12482	0.001077	0	0.177165
Mtr.38954.1.S1_at	Mtr.38954.1	TC103902 /FEA = mRNA /DEF = weakly similar to UP/Q6EMC0 (Q6EMC0) Ferric-chelate reductase, partial (23%)	TC103902	885.9769	136.5601	125.1288	19.31496	0.00067	0	0.141233

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To identify genes that might be regulated directly by MtPAR, genes that were ‘repressed’ in the par mutants were compared with those induced in p35S::MtPAR lines relative to their appropriate controls (FIG. 9a). Twelve genes satisfied both criteria and 8 of these encode enzymes involved in PA and anthocyanin biosynthesis (FIG. 9a, FIG. 10a). Amongst

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these were genes encoding ANS and ANR, which carry out the last two steps in the synthesis of epicatechin, which is the building block for PAs in *Medicago* (FIG. 10b). MtGEA probeset IDs for enzymes shown in FIG. 10b are listed in Table 4.

TABLE 4

List of probeset IDs for enzymes of FIG. 10b.			
Probesets	Name	BINS	Target Description
Mtr.12556.1.S1_at	4CL	16.2.1.3	TC95226/FEA = mRNA/DEF = similar to UP Q9SMT7 (Q9SMT7) 4-coumarate-CoA ligase-like protein (Adenosine monophosphate binding protein 3 AMPBP3), partial (82%)
Mtr.13904.1.S1_at	4CL	16.2.1.3	TC99584/FEA = mRNA/DEF = similar to UP Q9M0X9 (Q9M0X9) 4-coumarate-CoA ligase-like protein, partial (29%)
Mtr.2048.1.S1_at	4CL	16.2.1.3	BF004585/FEA = mRNA/DEF = similar to UP 4CL1_SOYBN (P31686) 4-coumarate--CoA ligase 1 (4CL 1) (4-coumaroyl-CoA synthase 1) (Clone 4CL14) (Fragment), partial (25%)
Mtr.25611.1.S1_at	4CL	16.2.1.3	1438.m00031/FEA = mRNA/DEF = AC144503.17 28902 32269 mth2-13f22 similar to UP Q8W558 (Q8W558) 4-coumarate: CoA ligase (EC 6.2.1.12)
Mtr.32034.1.S1_at	4CL	16.2.1.3	AL389862/FEA = mRNA/DEF = similar to UP Q9M0X9 (Q9M0X9) 4-coumarate-CoA ligase-like protein, partial (31%)
Mtr.32035.1.S1_at	4CL	16.2.1.3	AL389863/FEA = mRNA/DEF = similar to UP Q42880 (Q42880) 4-coumarate: CoA ligase, partial (4%)
Mtr.33696.1.S1_at	4CL	16.2.1.3	BI264867/FEA = mRNA/DEF = similar to UP Q84P23 (Q84P23) 4-coumarate-CoA ligase-like protein, partial (13%)
Mtr.36885.1.S1_at	4CL	16.2.1.3	CX540116/FEA = mRNA/DEF = similar to UP Q9M0X9 (Q9M0X9) 4-coumarate-CoA ligase-like protein, partial (2%)
Mtr.41031.1.S1_at	4CL	16.2.1.3	TC108579/FEA = mRNA/DEF = homologue to PIR PQ0772 PQ0772 4-coumarate-CoA ligase (clone GM4CL1B) - soybean (fragment) { <i>Glycine max</i> }, partial (62%)
Mtr.42330.1.S1_at	4CL	16.2.1.3	TC111254/FEA = mRNA/DEF = weakly similar to UP O49414 (O49414) 4-coumarate-CoA ligase-like (4-coumarate CoA ligase isoform 7), partial (37%)
Mtr.42337.1.S1_at	4CL	16.2.1.3	TC111271/FEA = mRNA/DEF = similar to UP Q8S5C1 (Q8S5C1) 4-coumarate: CoA ligase isoenzyme 2, partial (48%)
Mtr.43335.1.S1_at	4CL	16.2.1.3	TC95093/FEA = mRNA/DEF = similar to UP Q8S564 (Q8S564) 4-coumarate: coenzyme A ligase, partial (95%)
Mtr.44778.1.S1_at	4CL	16.2.1.3	TC98074/FEA = mRNA/DEF = similar to UP Q84P23 (Q84P23) 4-coumarate-CoA ligase-like protein, partial (26%)
Mtr.45561.1.S1_at	4CL	16.2.1.3	TC99926/FEA = mRNA/DEF = similar to UP Q9FGW4 (Q9FGW4) 4-coumarate-CoA ligase-like protein (4-coumarate CoA ligase isoform 4) (At5g63380), partial (35%)
Mtr.4878.1.S1_at	4CL	16.2.1.3	AL388151/FEA = mRNA/DEF = similar to UP Q84P23 (Q84P23) 4-coumarate-CoA ligase-like protein, partial (2%)
Mtr.9435.1.S1_at	4CL	16.2.1.3	TC103345/FEA = mRNA/DEF = weakly similar to UP Q9M0X9 (Q9M0X9) 4-coumarate-CoA ligase-like protein, partial (40%)
Mtr.9793.1.S1_at	4CL	16.2.1.3	TC104410/FEA = mRNA/DEF = similar to UP Q84P21 (Q84P21) 4-coumarate-CoA ligase-like protein, partial (41%)
Mtr.44985.1.S1_at	ANR	NA	TC98546/FEA = mRNA/DEF = UP Q84XT1 (Q84XT1) Anthocyanidin reductase, complete
Mtr.7129.1.S1_at	ANR	NA	CX542303/FEA = mRNA/DEF = UP Q84XT1 (Q84XT1) Anthocyanidin reductase, partial (13%)
Mtr.14017.1.S1_at	ANS	NA	TC99980/FEA = mRNA/DEF = weakly similar to UP LDOX_ARATH (Q96323) Leucoanthocyanidin dioxygenase (LDOX) (Leucoanthocyanidin oxygenase) (Leucoanthocyanidin hydroxylase) (Anthocyanidin synthase) (ANS), partial (19%)
Mtr.28774.1.S1_at	ANS	16.8.1.1001	BM812824/FEA = mRNA/DEF = similar to UP Q6PTC5 (Q6PTC5) Anthocyanidin synthase, partial (53%)
Mtr.38650.1.S1_at	ANS	NA	TC103244/FEA = mRNA/DEF = weakly similar to UP Q5UL08 (Q5UL08) Anthocyanidin synthase, partial (25%)
Mtr.10779.1.S1_at	CHI	16.8.2	TC107882/FEA = mRNA/DEF = similar to UP CFI_VITVI (P51117) Chalcone--flavonone isomerase (Chalcone isomerase), partial (90%)
Mtr.37080.1.S1_at	CHI	16.8.2	TC112171/FEA = mRNA/DEF = similar to UP Q9FUH5 (Q9FUH5) Chalcone isomerase 1 (Fragment), partial (20%)
Mtr.37412.1.S1_at	CHI	16.8.2	TC100603/FEA = mRNA/DEF = similar to UP Q9FLC7 (Q9FLC7) Similarity to chalcone-flavonone isomerase, partial (69%)
Mtr.37412.1.S1_s_at	CHI	16.8.2	TC100603/FEA = mRNA/DEF = similar to UP Q9FLC7 (Q9FLC7) Similarity to chalcone-flavonone isomerase, partial (69%)
Mtr.37413.1.S1_s_at	CHI	16.8.2	TC100605/FEA = mRNA/DEF = similar to UP Q9FLC7 (Q9FLC7) Similarity to chalcone-flavonone isomerase, partial (52%)
Mtr.40331.1.S1_at	CHI	16.8.2	TC107065/FEA = mRNA/DEF = weakly similar to UP CFI_PHAVU (P14298) Chalcone--flavonone isomerase (Chalcone isomerase), partial (94%)
Mtr.4347.1.S1_s_at	CHI	16.8.2	AJ497605/FEA = mRNA/DEF = similar to UP CFI_IPOPU (O22604) Chalcone--flavonone isomerase (Chalcone isomerase), partial (24%)
Mtr.6282.1.S1_at	CHI	16.8.2	BQ137326/FEA = mRNA/DEF = similar to UP Q9FLC7 (Q9FLC7) Similarity to chalcone-flavonone isomerase, partial (9%)
Mtr.8531.1.S1_at	CHI	16.8.2	TC100522/FEA = mRNA/DEF = homologue to UP CFI1_MEDSA (P28012) Chalcone--flavonone isomerase 1 (Chalcone isomerase 1), complete
Mtr.8555.1.S1_at	CHI	16.8.2	TC100604/FEA = mRNA/DEF = similar to UP Q9FLC7 (Q9FLC7) Similarity to chalcone-flavonone isomerase, partial (58%)
Mtr.10368.1.S1_at	CHS	16.8.2	TC106536/FEA = mRNA/DEF = homologue to UP CHS8_MEDSA (P30076) Chalcone synthase 8 (Naringenin-chalcone synthase 8), complete
Mtr.10369.1.S1_at	CHS	16.8.2	TC106538/FEA = mRNA/DEF = similar to UP Q5WM49 (Q5WM49) Chalcone synthase, complete

TABLE 4-continued

List of probeset IDs for enzymes of FIG. 10b.			
Probesets	Name	BINS	Target Description
Mtr.14428.1.S1_at	CHS	16.8.2.1	IMGAG 1115.m00011/FEA = mRNA/DEF = Naringenin-chalcone synthase; Type III polyketide synthase AC146683.9.101 54170 52902 mth2-179n10 Jan. 13, 2005
Mtr.14428.1.S1_x_at	CHS	16.8.2.1	IMGAG 1115.m00011/FEA = mRNA/DEF = Naringenin-chalcone synthase; Type III polyketide synthase AC146683.9.101 54170 52902 mth2-179n10 Jan. 13, 2005
Mtr.17612.1.S1_x_at	CHS	16.8.2.1	IMGAG 918.m00012/FEA = mRNA/DEF = Naringenin-chalcone synthase; Type III polyketide synthase AC137823.43.121 61682 60352 mth2-14c17 Jan. 13, 2005
Mtr.17616.1.S1_x_at	CHS	16.8.2.1	IMGAG 918.m00018/FEA = mRNA/DEF = Naringenin-chalcone synthase; Type III polyketide synthase AC137823.43.181 72290 73620 mth2-14c17 Jan. 13, 2005
Mtr.17621.1.S1_x_at	CHS	16.8.2.1	IMGAG 918.m00021/FEA = mRNA/DEF = Naringenin-chalcone synthase; Type III polyketide synthase AC137823.43.211 79927 81521 mth2-14c17 Jan. 13, 2005
Mtr.20185.1.S1_at	CHS	16.8.2.1	IMGAG 1104.m00013/FEA = mRNA/DEF = Naringenin-chalcone synthase; Type III polyketide synthase AC146575.3.131 82667 81204 mth2-145m4 Jan. 13, 2005
Mtr.20185.1.S1_x_at	CHS	16.8.2.1	IMGAG 1104.m00013/FEA = mRNA/DEF = Naringenin-chalcone synthase; Type III polyketide synthase AC146575.3.131 82667 81204 mth2-145m4 Jan. 13, 2005
Mtr.20187.1.S1_at	CHS	16.8.2.1	IMGAG 1104.m00017/FEA = mRNA/DEF = Naringenin-chalcone synthase; Type III polyketide synthase AC146575.3.171 96668 95373 mth2-145m4 Jan. 13, 2005
Mtr.20187.1.S1_x_at	CHS	16.8.2.1	IMGAG 1104.m00017/FEA = mRNA/DEF = Naringenin-chalcone synthase; Type III polyketide synthase AC146575.3.171 96668 95373 mth2-145m4 Jan. 13, 2005
Mtr.20464.1.S1_x_at	CHS	16.8.2.1	IMGAG 1111.m00013/FEA = mRNA/DEF = Naringenin-chalcone synthase; Type III polyketide synthase AC146650.13.121 79531 80861 mth2-14j5 Jan. 13, 2005
Mtr.20567.1.S1_at	CHS	16.2.99	IMGAG 1115.m00010/FEA = mRNA/DEF = Type III polyketide synthase; Naringenin-chalcone synthase AC146683.9.91 50180 48876 mth2-179n10 Jan. 13, 2005
Mtr.28714.1.S1_at	CHS	16.8.2	BI311259/FEA = mRNA/DEF = homologue to PRF 1609233A 226868 1609233A chalcone synthase 3. { <i>Sinapis alba</i> };, partial (12%)
Mtr.31570.1.S1_at	CHS	16.8.2	AL370397/FEA = mRNA/DEF = weakly similar to UP CFI_PUELO (Q43056) Chalcone--flavonone isomerase (Chalcone isomerase), partial (64%)
Mtr.32188.1.S1_x_at	CHS	16.8.2	AW684295/FEA = mRNA/DEF = homologue to UP CHS9_MEDSA (P30077) Chalcone synthase 9 (Naringenin-chalcone synthase 9), partial (24%)
Mtr.33961.1.S1_at	CHS	16.8.2	BQ135500/FEA = mRNA/DEF = similar to UP Q5XVS6 (Q5XVS6) Chalcone synthase, partial (11%)
Mtr.33982.1.S1_at	CHS	16.8.2	BQ135569/FEA = mRNA/DEF = weakly similar to UP CHS3_PEA (O23883) Chalcone synthase 3 (Naregenin-chalcone synthase 3), partial (10%)
Mtr.36618.1.S1_at	CHS	16.8.2	BQ143805/FEA = mRNA/DEF = similar to UP Q9SLY0 (Q9SLY0) Chalcone synthase, partial (3%)
Mtr.40122.1.S1_s_at	CHS	16.8.2	TC106554/FEA = mRNA/DEF = homologue to UP CHS4_MEDSA (P30075) Chalcone synthase 4 (Naringenin-chalcone synthase 4) (CHS12-1), partial (82%)
Mtr.40123.1.S1_at	CHS	16.8.2	TC106555/FEA = mRNA/DEF = homologue to UP CHS4_MEDSA (P30075) Chalcone synthase 4 (Naringenin-chalcone synthase 4) (CHS12-1), partial (34%)
Mtr.43713.1.S1_at	CHS	16.8.2	TC95902/FEA = mRNA/DEF = similar to UP O80407 (O80407) Chalcone synthase, partial (95%)
Mtr.44617.1.S1_at	CHS	16.8.2	TC97724/FEA = mRNA/DEF = weakly similar to GB AAB35812.1 1246019 S80554 chalcone synthase { <i>Arabidopsis</i> };, partial (31%)
Mtr.44844.1.S1_at	CHS	16.8.2	TC98216/FEA = mRNA/DEF = homologue to UP Q41399 (Q41399) Chalcone reductase, partial (69%)
Mtr.45667.1.S1_x_at	CHS	16.2.99	IMGAG 918.m00023/FEA = mRNA/DEF = Type III polyketide synthase; Naringenin-chalcone synthase AC137823.43.231 84744 86235 mth2-14c17 Jan. 13, 2005
Mtr.49572.1.S1_s_at	CHS	16.8.2.1	IMGAG 1104.m00016/FEA = mRNA/DEF = Naringenin-chalcone synthase; Type III polyketide synthase AC146575.3.161 92557 91179 mth2-145m4 Jan. 13, 2005
Mtr.49572.1.S1_x_at	CHS	16.8.2.1	IMGAG 1104.m00016/FEA = mRNA/DEF = Naringenin-chalcone synthase; Type III polyketide synthase AC146575.3.161 92557 91179 mth2-145m4 Jan. 13, 2005
Mtr.49576.1.S1_at	CHS	16.2.99	IMGAG 1104.m00010/FEA = mRNA/DEF = Ankyrin; Naringenin-chalcone synthase AC146575.3.101 65210 64569 mth2-145m4 Jan. 13, 2005
Mtr.52044.1.S1_s_at	CHS	16.8.2.1	IMGAG 848.m00025/FEA = mRNA/DEF = Naringenin-chalcone synthase AC134242.17.251 108327 109841 mth2-10p20 Jan. 13, 2005
Mtr.6212.1.S1_at	CHS	16.8.2	BQ135426/FEA = mRNA/DEF = weakly similar to UP CHS3_PEA (O23883) Chalcone synthase 3 (Naregenin-chalcone synthase 3), partial (9%)
Mtr.6221.1.S1_at	CHS	16.8.2	BQ135487/FEA = mRNA/DEF = similar to GB BAA01513.1 391783 PEACHS2 chalcone synthase { <i>Pisum sativum</i> };, partial (39%)
Mtr.38073.1.S1_at	DFR	16.8.4	TC102034/FEA = mRNA/DEF = UP Q6TQT1 (Q6TQT1) Dihydroflavanol-4-reductase 1, complete
Mtr.38756.1.S1_at	DFR	16.8.4	TC103465/FEA = mRNA/DEF = UP Q6TQT0 (Q6TQT0) Dihydroflavanol-4-reductase 2, complete
Mtr.4272.1.S1_at	DFR	16.8.4	AA660236/FEA = mRNA/DEF = similar to UP Q9FS36 (Q9FS36) Dihydroflavanol 4-reductase, partial (9%)
Mtr.4272.1.S1_s_at	DFR	16.8.4	AA660236/FEA = mRNA/DEF = similar to UP Q9FS36 (Q9FS36) Dihydroflavanol 4-reductase, partial (9%)
Mtr.13960.1.S1_at	F3H	16.8.4	TC99759/FEA = mRNA/DEF = similar to UP Q84JJ4 (Q84JJ4) Flavonoid 3'-hydroxylase (Fragment), partial (63%)
Mtr.32642.1.S1_at	F3H	16.8.4	BE248260/FEA = mRNA/DEF = similar to UP C755_EUSGR (Q96418) Flavonoid 3',5'-hydroxylase (F3'5'H) (Cytochrome P450 75A5), partial (18%)
Mtr.35691.1.S1_at	F3H	16.8.4	TC111173/FEA = mRNA/DEF = weakly similar to UP Q9STI0 (Q9STI0) Flavonoid 3',5'-hydroxylase-like protein (At4g12310), partial (9%)
Mtr.36333.1.S1_at	F3H	16.8.4	BE248436/FEA = mRNA/DEF = similar to UP Q84JJ4 (Q84JJ4) Flavonoid 3'-hydroxylase (Fragment), partial (21%)
Mtr.38450.1.S1_at	F3H	16.8.3	TC102835/FEA = mRNA/DEF = weakly similar to GB AAT44124.1 48431269 AY550120 F3H-like protein { <i>Saussurea medusa</i> };, partial (27%)

TABLE 4-continued

List of probeset IDs for enzymes of FIG. 10b.			
Probesets	Name	BINS	Target Description
Mtr.38814.1.S1_at	F3H	16.8.4	TC103590/FEA = mRNA/DEF = weakly similar to UP Q9STH8 (Q9STH8) Flavonoid 3',5'-hydroxylase like protein (Flavonoid 3,5-hydroxylase like protein), partial (33%)
Mtr.42668.1.S1_at	F3H	16.8.3	TC112116/FEA = mRNA/DEF = weakly similar to GB AAT44124.1 48431269 AY550120 F3H-like protein { <i>Saussurea medusa</i> };, partial (32%)
Mtr.45258.1.S1_at	F3H	16.8.4	TC99191/FEA = mRNA/DEF = similar to UP Q76LL4 (Q76LL4) Flavonoid 3',5'-hydroxylase, partial (53%)
Mtr.6409.1.S1_at	F3H	16.8.4	BQ141925/FEA = mRNA/DEF = similar to UP Q6J210 (Q6J210) Flavonoid 3' 5'-hydroxylase, partial (2%)
Mtr.7094.1.S1_at	F3H	16.8.4	CX540205/FEA = mRNA/DEF = homologue to UP Q9FPN3 (Q9FPN3) Flavonoid 3',5'-hydroxylase, partial (13%)
Mtr.9446.1.S1_at	F3H	16.8.3	TC103378/FEA = mRNA/DEF = weakly similar to UP Q9FLV0 (Q9FLV0) Flavanone 3-hydroxylase-like protein, partial (28%)
Mtr.9867.1.S1_at	F3H	16.8.3	TC104677/FEA = mRNA/DEF = weakly similar to GB AAT44124.1 48431269 AY550120 F3H-like protein { <i>Saussurea medusa</i> };, partial (24%)
Mtr.24709.1.S1_at	FLS	NA	1761.m00046/FEA = mRNA/DEF = AC152349.3 81074 80260 mth2-52p10 weakly similar to TAIR gene: 1005714550-GOpep .2 68410.m02179 flavonol synthase family contains similarity to flavonol synthase
Mtr.38256.1.S1_s_at	FLS	16.8.4	TC102386/FEA = mRNA/DEF = weakly similar to UP Q84UT8 (Q84UT8) Flavonol synthase, partial (25%)
Mtr.44957.1.S1_at	FLS	16.8.4	TC98484/FEA = mRNA/DEF = weakly similar to UP FLS_EUSGR (Q9M547) Flavonol synthase (FLS), partial (50%)
Mtr.10553.1.S1_at	GT	26.2	TC107173/FEA = mRNA/DEF = weakly similar to UP Q6VAB3 (Q6VAB3) UDP-glycosyltransferase 85A8, partial (27%)
Mtr.21996.1.S1_x_at	GT	NA	1578.m00031/FEA = mRNA/DEF = AC124966.27 4823 6271 mth2-8i15 weakly similar to UP Q8S996 (Q8S996) Glucosyltransferase-13 (Fragment)
Mtr.24410.1.S1_at	GT	NA	1739.m00044/FEA = mRNA/DEF = AC151424.10 31908 29993 mth2-101c17 similar to UP Q8S996 (Q8S996) Glucosyltransferase-13 (Fragment)
Mtr.31819.1.S1_at	GT	NA	AL381855/FEA = mRNA/DEF = weakly similar to UP Q9T081 (Q9T081) UDP rhamnose--anthocyanidin-3-glucoside rhamnosyltransferase-like protein (At4g27570), partial (17%)
Mtr.44505.1.S1_at	GT	26.2	TC97488/FEA = mRNA/DEF = similar to UP Q8S9A0 (Q8S9A0) Glucosyltransferase-9, partial (70%)
Mtr.45072.1.S1_at	GT	NA	TC98718/FEA = mRNA/DEF = weakly similar to UP LGT_CITUN (Q9MB73) Limonoid UDP-glucosyltransferase (Limonoid glucosyltransferase) (Limonoid GTase) (LGTase), partial (32%)
Mtr.20055.1.S1_at	LAR	NA	IMGAG 1099.m00001/FEA = mRNA/DEF = leucoanthocyanidin reductase (ec 1.17.1.3) (leucocyanidin reductase) AC146570.4.1 1634 5066 mth2-103j7 Jan. 13, 2005
Mtr.10404.1.S1_at	PAL	16.2.1.1	TC106670/FEA = mRNA/DEF = homologue to UP PALY_MEDSA (P27990) Phenylalanine ammonia-lyase, partial (19%)
Mtr.38612.1.S1_at	PAL	16.2.1.1	TC103174/FEA = mRNA/DEF = similar to PRF 1807329B 228615 1807329B Phe ammonia lyase. { <i>Phaseolus vulgaris</i> };, partial (28%)
Mtr.40166.1.S1_s_at	PAL	16.2.1.1	TC106668/FEA = mRNA/DEF = homologue to UP PALY_MEDSA (P27990) Phenylalanine ammonia-lyase, partial (28%)
Mtr.40167.1.S1_s_at	PAL	16.2.1.1	TC106669/FEA = mRNA/DEF = homologue to UP PALY_MEDSA (P27990) Phenylalanine ammonia-lyase, complete
Mtr.40168.1.S1_at	PAL	16.2.1.1	TC106671/FEA = mRNA/DEF = similar to UP Q9M567 (Q9M567) Phenylalanine ammonia-lyase 2, partial (15%)
Mtr.50478.1.S1_at	PAL	16.2.1.1	IMGAG 968.m00002/FEA = mRNA/DEF = Phenylalanine/histidine ammonia-lyase; L-Aspartase-like; Phenylalanine ammonia-lyase AC140028.21.21 6624 2477 mth2-7e24 Jan. 13, 2005
Mtr.51909.1.S1_at	PAL	16.2.1.1	IMGAG 843.m00022/FEA = mRNA/DEF = Phenylalanine/histidine ammonia-lyase; L-Aspartase-like; Phenylalanine ammonia-lyase AC133709.10.211 119802 113450 mth2-7b3 Jan. 13, 2005
Mtr.9254.1.S1_at	PAL	16.2.1.1	TC102823/FEA = mRNA/DEF = similar to PRF 1807329B 228615 1807329B Phe ammonia lyase. { <i>Phaseolus vulgaris</i> };, partial (47%)
Mtr.20924.1.S1_at	TT2	27.3.32.1	IMGAG 1132.m00008/FEA = mRNA/DEF = Myb, DNA-binding; Homeodomain-like AC146760.13.71 50869 52550 mth2-174d3 Jan. 13, 2005
Mtr.22479.1.S1_at	TT8	16.8.1.1001	1606.m00039/FEA = mRNA/DEF = AC135317.10 9174 16609 mth2-10p4 weakly similar to UP Q9FEA1 (Q9FEA1) Anthocyanin 1
Mtr.253.1.S1_at	TT8	27.3.10	1802.m00045/FEA = mRNA/DEF = CR932963.1 77295 81200 mth2-115p22 weakly similar to UP O81348 (O81348) Symbiotic ammonium transporter
Mtr.31614.1.S1_at	TTG1	NA	AL372205/FEA = mRNA/DEF = similar to UP Q8LSJ3 (Q8LSJ3) WD-repeat protein GhTTG1, partial (8%)
Mtr.39774.1.S1_at	TTG1	NA	TC105711/FEA = mRNA/DEF = homologue to UP Q9M610 (Q9M610) Ttg1-like protein, partial (46%)

To assess the impact of the par mutation on the flavonoid pathway as a whole, we performed metabolite profiling using ultra-performance liquid chromatography coupled to electro-spray ionization quadrupole time of flight mass spectrometry

(HPLC-ESI-QTOF-MS). Out of 74 secondary metabolites identified in mature seeds, 22 were altered significantly in amount in par mutants compared to wild-type controls (See Table 5).

TABLE 5

UPLC Mass spectrometry results.						
Field Name	Field Name	AVR WT	SD WT	AVR Mut	SD Mut	T-Test
163.0385	p-Coumaric acid (Aut_DH)	0.414033	0.032933	0.353565	0.066928	coumaric product
161.0239	umbelliferone (Aut_DH))	98.90151	1.901535	100.5152	1.20757	
		99.31554	1.890719	100.8688	1.228534	
		1	0.019037	1.015639	0.01237	0.039054093
451.1235	EpicatechinGlucoside (Aut_DH)	2.170932	0.229599	1.211214	0.123314	
289.0726	Epicatechin (Aut_DH))	0.649441	0.081218	0.314479	0.042761	
		2.820373	0.303687	1.525693	0.143791	3.67702E-08
		1	0.107676	0.540954	0.050983	
609.1505	luteolin-3-7-di-O-glu (Aut_DH)	0.338314	0.144366	0.815536	0.229098	
609.1476	luteolin-3,7-O-glu (Aut_DH))	0.344542	0.146416	0.819365	0.227313	Flavonol glycosides
607.1331	Rutin(AUT_DH)	1.065182	0.464067	2.687139	0.875834	
607.1297	Kaempferol Glucuronide Rhamnose (Put_YDS)	1.057552	0.469356	2.705964	0.892704	
593.1505	kempferol-3-O-rutinoside (Aut_DH)	0.649113	0.124604	0.505343	0.025441	Flavonol glycosides
271.0606	Narigenin-7-O-glucoside-aglycone (Aut_DH)	0.27681	0.053653	0.195376	0.048142	
431.0962	apigenin-7-O-glu (Aut_DH) or	6.948113	1.442785	5.433148	0.635942	
		10.67962	1.827922	13.16187	2.811249	0.033908428
		1	0.17116	1.232428	0.263235	
455.3538	Soyasapogenol E	2.853693	0.714358	1.503997	0.090121	
663.3756	Hex-Medicagenic Acid (Put_DH)	1.567111	0.342674	1.046466	0.083917	Saponins
793.4335	HexA-Hex-Soyasapogenol E (Put_MB)	1.118791	0.070432	0.937857	0.110712	
793.4389	HexA-Hex-Soy E (Put_DH)	1.109246	0.061841	0.935179	0.113136	
925.4822	Hex-Hex-Rha-SoyE (Put_DH)	0.632367	0.40404	1.040187	0.163535	Saponins
501.3228	Mediagenic Acid (Put_DH)	0.522835	0.579536	0.075502	0.029033	
957.506	Hex-Hex-Hex-Hederagenin (Put_MB)	0.388559	0.153379	0.93891	0.713847	
957.5068	Hex-Hex-Hex-Hederagenin (Put_DH)	0.369966	0.173381	0.888785	0.749956	Saponins
		8.562569	1.230207	7.366883	1.493789	
		1	0.143673	0.860359	0.174456	

These metabolites belonged mainly to four classes of compounds: coumaric acid-related compounds (2 metabolites), triterpene saponins (8), epicatechins (2) and flavonol glycosides (7). Although the amount of individual saponins changed in the par mutants, the total amount of saponins was not significantly different between mutants and their wild-type siblings. The same was true of the coumaric acid-related compounds. In contrast, total epicatechin content was substantially lower by 45.9% and flavonol glycoside content higher by 23.2% in par mutants than in wild-type controls (FIG. 10c). The reduced amount of epicatechin in the par mutants mirrored the reduced level soluble PAs in these mutants (FIG. 10c).

Taken together, the results of genetic, transcriptomic and metabolomic analyses indicate that MtPAR plays a rather specific role as a positive regulator of PA biosynthesis in *M. truncatula*.

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Example 4

MtPAR Acts Upstream of TTG1

Previously, a WD40 repeat protein, orthologous to *Arabidopsis* TTG1, was identified in *M. truncatula* and called MtWD40-1 (Pang et al., 2009). *M. truncatula* wd40-1 mutants displayed a drastic decrease of soluble and insoluble PA (Pang et al., 2009). However, over-expression of MtWD40-1 in *M. truncatula* hairy roots resulted in an increase of anthocyanin content without affecting PA content. Published transcriptome data of wd40-1 mutants (Pang et al., 2009) were compared to those of par mutants. Of the 38 genes that were down-regulated in 20 DAP seeds of par mutants compared to wild-type controls, 16 were also down-regulated in wd40-1 mutant seeds collected at 16 DAP. Moreover, almost all (14/16) are related to flavonoid biosynthesis according to Genebins ontology (Goffard & Weiler, 2007); list and annotations are shown in Table 6 (list of probesets down-regulated in par and ttg1 mutant lines).

TABLE 6

Common probesets down-regulated in par and ttg1 mutant lines.	
Probesets	Target Description
Mtr.20567.1.S1_at	IMGAG 1115.m00010/FEA = mRNA/DEF = Type III polyketide synthase; Naringenin-chalcone synthase AC146683.9.91 50180 48876 mth2-179n10 Jan. 13, 2005
Mtr.36333.1.S1_at	BE248436/FEA = mRNA/DEF = similar to UP Q84JJ4 (Q84JJ4) Flavonoid 3'-hydroxylase (Fragment), partial (21%)
Mtr.6517.1.S1_at	BQ147749/FEA = mRNA/DEF = similar to UP Q84J65 (Q84J65) Gray pubescence flavonoid 3'-hydroxylase, partial (49%)
Mtr.49572.1.S1_s_at	IMGAG 1104.m00016/FEA = mRNA/DEF = Naringenin-chalcone synthase; Type III polyketide synthase AC146575.3.161 92557 91179 mth2-145m4 Jan. 13, 2005
Mtr.20187.1.S1_x_at	IMGAG 1104.m00017/FEA = mRNA/DEF = Naringenin-chalcone synthase; Type III polyketide synthase AC146575.3.171 96668 95373 mth2-145m4 Jan. 13, 2005
Mtr.20187.1.S1_at	IMGAG 1104.m00017/FEA = mRNA/DEF = Naringenin-chalcone synthase; Type III polyketide synthase AC146575.3.171 96668 95373 mth2-145m4 Jan. 13, 2005
Mtr.14017.1.S1_at	TC99980/FEA = mRNA/DEF = weakly similar to UP LDOX_ARATH (Q96323) Leucoanthocyanidin dioxygenase (LDOX) (Leucoanthocyanidin oxygenase) (Leucoanthocyanidin hydroxylase) (Anthocyanidin synthase) (ANS), partial (19%)
Mtr.39897.1.S1_at	TC105988/FEA = mRNA/DEF = similar to UP P93697 (P93697) CPRD12 protein, partial (61%)

TABLE 6-continued

Common probesets down-regulated in par and ttg1 mutant lines.	
Probesets	Target Description
Mtr.49572.1.S1__x__at	IMGAG 1104.m00016/FEA = mRNA/DEF = Naringenin-chalcone synthase; Type III polyketide synthase AC146575.3.161 92557 91179 mth2-145m4 Jan. 13, 2005
Mtr.21996.1.S1__x__at	1578.m00031/FEA = mRNA/DEF = AC124966.27 4823 6271 mth2-8i15 weakly similar to UP Q8S996 (Q8S996) Glucosyltransferase-13 (Fragment)
Mtr.44985.1.S1__at	TC98546/FEA = mRNA/DEF = UP Q84XT1 (Q84XT1) Anthocyanidin reductase, complete
Mtr.28714.1.S1__at	BI311259/FEA = mRNA/DEF = homologue to PRF 1609233A 226868 1609233A chalcone synthase 3. { <i>Sinapis alba</i> };, partial (12%)
Mtr.16432.1.S1__at	IMGAG 824.m00011/FEA = mRNA/DEF = Myb, DNA-binding; Homeodomain-like AC129092.13.101 59248 60901 mth2-17n16 Jan. 13, 2005
Mtr.41031.1.S1__at	TC108579/FEA = mRNA/DEF = homologue to PIR PQ0772 PQ0772 4-coumarate-CoA ligase (clone GM4CL1B) - soybean (fragment) { <i>Glycine max</i> };, partial (62%)
Mtr.10917.1.S1__at	TC108343/FEA = mRNA/DEF = similar to UP C773__SOYBN (O48928) Cytochrome P450 77A3, partial (95%)
Mtr.50478.1.S1__at	IMGAG 968. m00002/FEA = mRNA/DEF = Phenylalanine/histidine ammonia-lyase; L-Aspartase-like; Phenylalanine ammonia-lyase AC140028.21.21 6624 2477 mth2-7e24 Jan. 13, 2005

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To test whether MtPAR and MtWD40-1 act via a common regulatory pathway to induce target genes, WD40-1 gene expression was measured in par mutants, by qRT-PCR. Significantly, WD40-1 transcript levels were between 15 and 50 times lower in par mutant seeds than in wild-type sibling seed controls at 20 DAP (FIG. 6c). In contrast, PAR transcript levels were unaffected by mutations in the WD40-1 gene in 16 DAP seeds (Pang et al., 2009). Conversely, MtPAR over-expression induced MtWD40-1 expression in *Medicago* hairy roots (FIG. 6b). A list of probesets up-regulated in hairy root transformants over-expressing PAR and 112 is given in Table 7.

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experimentation in light of the present disclosure. While the compositions and methods of this invention have been described in terms of preferred embodiments, it will be apparent to those of skill in the art that variations may be applied to the compositions and methods and in the steps or in the sequence of steps of the method described herein without departing from the concept, spirit and scope of the invention. More specifically, it will be apparent that certain agents which are both chemically and physiologically related may be substituted for the agents described herein while the same or similar results would be achieved. All such similar substitutes and modifications apparent to those skilled in the art are

TABLE 7

Probesets up-regulated in hairy root transformants over-expressing PAR and TT2.	
Probesets	Target Description
Mtr.47022.1.S1__s__at	1705.m00036/FEA = mRNA/DEF = AC148359.19 17939 18394 mth2-22k11 weakly similar to TAIR gene: 2181071-GOpep .1 68412.m00083 expressed protein wound-inducible protein wun1 protein - <i>Solanum</i>
Mtr.20567.1.S1__at	IMGAG 1115.m00010/FEA = mRNA/DEF = Type III polyketide synthase; Naringenin-chalcone synthase AC146683.9.91 50180 48876 mth2-179n10 Jan. 13, 2005
Mtr.33715.1.S1__at	BI265542/FEA = mRNA/DEF =
Mtr.25016.1.S1__at	1785.m00050/FEA = mRNA/DEF = AC155890.1 50797 51458 mth2-49p3
Mtr.14017.1.S1__at	TC99980/FEA = mRNA/DEF = weakly similar to UP LDOX__ARATH (Q96323) Leucoanthocyanidin dioxygenase (LDOX) (Leucocyanidin oxygenase) (Leucoanthocyanidin hydroxylase) (Anthocyanidin synthase) (ANS), partial (19%)
Mtr.1157.1.S1__s__at	1544.m00032/FEA = mRNA/DEF = AC149039.2 10370 11266 mth2-4g23 weakly similar to UP Q6WAY3 (Q6WAY3) Gag/pol polyprotein
Mtr.148.1.S1__s__at	1785.m00048/FEA = mRNA /DEF = AC155890.1 47822 48796 mth2-49p3
Mtr.11000.1.S1__at	TC108561/FEA = mRNA/DEF =
Mtr.6517.1.S1__at	BQ147749/FEA = mRNA/DEF = similar to UP Q84J65 (Q84J65) Gray pubescence flavonoid 3'-hydroxylase, partial (49%)
Mtr.17982.1.S1__s__at	IMGAG 932.m00012/FEA = mRNA/DEF = hypothetical protein AC138017.15.111 51242 50808 mth2-6i3 Jan. 13, 2005
Mtr.51818.1.S1__at	IMGAG 896.m00006/FEA = mRNA/DEF = predicted protein AC136840.24.51 30231 32005 mth2-33n3 Jan. 13, 2005
Mtr.15436.1.S1__at	IMGAG 786.m00019/FEA = mRNA/DEF = 2OG-Fe(II) oxygenase; Immunoglobulin/major histocompatibility complex AC125478.13.191 98375 97104 mth2-31i19 Jan. 13, 2005
Mtr.25672.1.S1__a__at	1446.m00048/FEA = mRNA/DEF = AC146752.23 87430 86695 mth2-62d4
Mtr.32965.1.S1__at	BF635325/FEA = mRNA/DEF = similar to UP Q9ZSP7 (Q9ZSP7) Cytochrome b5 DIF-F, partial (36%)
Mtr.9894.1.S1__at	TC104797/FEA = mRNA/DEF = weakly similar to UP Q9LQ75 (Q9LQ75) T1N6.22 protein, partial (48%)
Mtr.28737.1.S1__at	BI312112/FEA = mRNA/DEF = similar to UP Q8LIS8 (Q8LIS8) Homeodomain protein GhHOX1, partial (27%)
Mtr.20511.1.S1__s__at	IMGAG 1220.m00020/FEA = mRNA/DEF = hypothetical protein AC148758.19.191 94204 93893 mth2-50i17 Jan. 13, 2005
Mtr.27451.1.S1__at	BE124481/FEA = mRNA/DEF =
Mtr.16363.1.S1__s__at	IMGAG 868.m00002/FEA = mRNA/DEF = LQGC hypothetical protein AC135396.30.21 8440 9117 mth2-33o18 Jan. 13, 2005
Mtr.44300.1.S1__at	TC97086/FEA = mRNA/DEF = similar to UP Q9ZR88 (Q9ZR88) Bifunctional nuclease (Fragment), partial (93%)

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All of the compositions and methods disclosed and claimed herein can be made and executed without undue

deemed to be within the spirit, scope and concept of the invention as defined by the appended claims.

The references listed below are incorporated herein by reference to the extent that they supplement, explain, provide a background for, or teach methodology, techniques, and/or compositions employed herein.

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85        90        95
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Ala Asp Phe Phe Ile Asp Phe Asp His Gln Asp Gln Leu Met Val Gly
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Asp Asp Glu Ser Asn Ser Lys Ile Pro Gln Met Glu Asp His Lys Val
195       200       205
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210       215       220
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<211> LENGTH: 765

<212> TYPE: DNA

<213> ORGANISM: *Medicago truncatula*

<400> SEQUENCE: 2

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ataaagagag gccatatctc taccgacgaa gaagacatga tcataagact tcatcgtctt      240
cttggttaaca gatggtcttt gatagctaag agactaccag gacgaacaga caatgaaatc      300
aagaactact ggaataactaa tctgtcaaag aagttacaaa aacagccaac atcatcatca      360
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gcaccagaag ctccaaagcc taggagactg aaggctgttc atcaatacaa aattttggaa	480
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attgactttg atcatcaaga tcaattgatg gttggtgatg atgagtctaa ttcaaagatt	600
ccacaaatgg aagatcacaa ggtgagttca acaaatagta ctcatagttc atcatcacct	660
tctgatcatt gtcattcttt agcagagaaa ttgaccctc aagagatcct ttggatgtg	720
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<211> LENGTH: 2594

<212> TYPE: DNA

<213> ORGANISM: Medicago truncatula

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<220> FEATURE:
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<220> FEATURE:
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<220> FEATURE:
<223> OTHER INFORMATION: Synthetic primer

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<223> OTHER INFORMATION: Synthetic primer

<400> SEQUENCE: 14

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<210> SEQ ID NO 15
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<212> TYPE: DNA
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<220> FEATURE:
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<400> SEQUENCE: 15

accaactaca cgggtcggg 20

<210> SEQ ID NO 16
<211> LENGTH: 20
<212> TYPE: DNA
<213> ORGANISM: Artificial Sequence
<220> FEATURE:
<223> OTHER INFORMATION: Synthetic primer

<400> SEQUENCE: 16

gctacagccg gcaactccca 20

<210> SEQ ID NO 17
<211> LENGTH: 20
<212> TYPE: DNA
<213> ORGANISM: Artificial Sequence
<220> FEATURE:
<223> OTHER INFORMATION: Synthetic primer

<400> SEQUENCE: 17

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<210> SEQ ID NO 18
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<212> TYPE: DNA
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<400> SEQUENCE: 18

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<210> SEQ ID NO 19

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<212> TYPE: DNA

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<400> SEQUENCE: 22

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<212> TYPE: DNA

<213> ORGANISM: Artificial Sequence

<220> FEATURE:

<223> OTHER INFORMATION: Synthetic primer

<400> SEQUENCE: 23

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<210> SEQ ID NO 24

<211> LENGTH: 22

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<213> ORGANISM: Artificial Sequence

<220> FEATURE:

<223> OTHER INFORMATION: Synthetic primer

<400> SEQUENCE: 24

aggctttgga gcttctggtg ct

22

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The invention claimed is:

1. A DNA molecule comprising a DNA sequence selected from the group consisting of:

- (a) a sequence encoding the polypeptide sequence of SEQ ID NO:1;
- (b) a sequence comprising the sequence of SEQ ID NO:2;
- (c) a sequence that hybridizes to SEQ ID NO:2 under conditions of 1×SSC, and 65° C., wherein the sequence encodes a polypeptide that regulates flavonoid synthesis;
- (d) a sequence encoding a polypeptide with at least 85% amino acid identity to SEQ ID NO:1, wherein the polypeptide regulates flavonoid synthesis;
- (e) a sequence with at least 85% identity to SEQ ID NO:2, wherein the sequence encodes a polypeptide that regulates flavonoid synthesis; and

(f) a complement of a sequence of any of (a)-(e), wherein the DNA sequence is operably linked to a heterologous promoter.

2. The DNA molecule of claim 1, wherein the sequence has at least 90 percent sequence identity to the amino acid sequence of SEQ ID NO:1 or to the DNA sequence of SEQ ID NO:2.

3. The DNA molecule of claim 1, wherein the sequence has at least 95 percent sequence identity to the amino acid sequence of SEQ ID NO:1 or to the DNA sequence of SEQ ID NO:2.

4. A recombinant vector comprising the DNA molecule of claim 1.

5. The recombinant vector of claim 4, further comprising at least one additional sequence chosen from the group consisting of: a selectable marker, a leader sequence, a sequence encoding a polypeptide that allows for anthocyanin or proanthocyanidin biosynthesis, and a terminator.

6. The recombinant vector of claim 5, wherein the polypeptide that allows for anthocyanin or proanthocyanidin biosynthesis is selected from the group consisting of: phenylalanine ammonia-lyase (PAL), cinnamate 4-hydroxylase (C4H), 4-coumarate:CoA ligase (4CL), chalcone synthase (CHS), chalcone isomerase (CHI), flavanone 3-hydroxylase (F3H), dihydroflavonol reductase (DFR), anthocyanidin synthase (ANS), leucoanthocyanidin reductase (LAR), anthocyanidin reductase (ANR), and a proanthocyanidin or anthocyanidin glucosyltransferase (GT).

7. The recombinant vector of claim 4, wherein the promoter is a plant developmentally-regulated, organelle-specific, inducible, tissue-specific, constitutive, or cell-specific promoter.

8. A transgenic plant cell or plant part comprising the DNA molecule of claim 1.

9. A transgenic plant comprising the DNA molecule of claim 1.

10. The transgenic plant of claim 9, wherein the plant is a *Medicago* plant.

11. The transgenic plant of claim 10, wherein the plant expresses the selected DNA and exhibits altered proanthocyanidin biosynthesis in selected tissues relative to those tissues in a second plant that differs from the transgenic plant only in that the selected DNA is absent.

12. The transgenic plant of claim 9, further defined as transformed with a selected DNA comprising a sequence encoding a proanthocyanidin regulatory polypeptide selected

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from the group consisting of SEQ ID NO:1, and a sequence with at least 90% sequence similarity to SEQ ID NO:1, having anthocyanin or proanthocyanidin biosynthesis regulatory activity.

13. The transgenic plant of claim 9, further defined as transformed with a selected DNA sequence complementary to at least 19 contiguous nucleotides of SEQ ID NO:2.

14. The transgenic plant of claim 13, further defined as transformed with a DNA sequence comprising at least 21 contiguous nucleotides complementary to SEQ ID NO: 2.

15. The transgenic plant of claim 13, wherein the selected DNA sequence comprises the complement of SEQ ID NO:2, or a fragment thereof.

16. The transgenic plant of claim 9, further defined as transformed with a DNA sequence encoding the polypeptide of SEQ ID NO:1.

17. The transgenic plant of claim 9, further defined as a forage crop.

18. The transgenic plant of claim 17, wherein the plant is a forage legume.

19. The transgenic plant of claim 18, wherein the forage legume is alfalfa (*Medicago sativa*).

20. The transgenic plant of claim 9, further defined as a fertile R0 transgenic plant.

21. The transgenic plant of claim 9, further defined as a progeny plant of any generation of a fertile R0 transgenic plant, wherein the transgenic plant comprises the selected DNA.

22. The transgenic plant of claim 9, wherein the plant is further defined as comprising a transgenic sequence that down-regulates proanthocyanidin biosynthesis.

23. A seed of the transgenic plant of claim 9, comprising the DNA molecule of claim 1.

24. A method of producing a plant with increased proanthocyanidin biosynthesis, comprising expressing in the plant the DNA molecule of claim 1.

25. The method of claim 24, wherein the plant further comprises a recombinant vector of claim 4.

26. The method of claim 24, wherein the DNA molecule is introduced into the plant by plant breeding.

27. The method of claim 24, wherein the DNA molecule is introduced into the plant by genetic transformation of the plant.

28. The method of claim 24, wherein the promoter is a constitutive or tissue specific promoter.

29. The method of claim 24, wherein the plant is a forage crop plant.

30. The method of claim 29, wherein the plant is a forage legume.

31. The method of claim 30, wherein the plant is alfalfa.

32. A method of making food or feed for human or animal consumption comprising:

- (a) obtaining the plant of claim 9;
- (b) growing the plant under plant growth conditions to produce plant tissue from the plant; and
- (c) preparing food or feed for human or animal consumption from the plant tissue.

33. The method of claim 32, wherein preparing food comprises harvesting the plant tissue.

34. The method of claim 32, wherein the food is hay, silage, starch, protein, meal, flour or grain.

* * * * *